Yield Potential, Yield Trends, and Global Food Security in a Changing Climate

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Energy, Land and Water in the Context of a Changing Climate

University of Nebraska Lincoln

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Topics

- Food security – global megatrends
- Yield potential and yield gap

Will business as usual meet projected global food demand? If won't do it, what is needed?

What is Food Security?

- **When all people at all times have physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life (USAID, FAO, WHO)**
  - **Availability** (sufficient quantity and quality)
  - Access (affordability, functioning markets)
  - Safety and sanitation
  - **Stability** (avoid “feast and famine” cycles)
- **Research on *Quantitative Food Security directly* addresses availability, and affordability and nutrition indirectly**

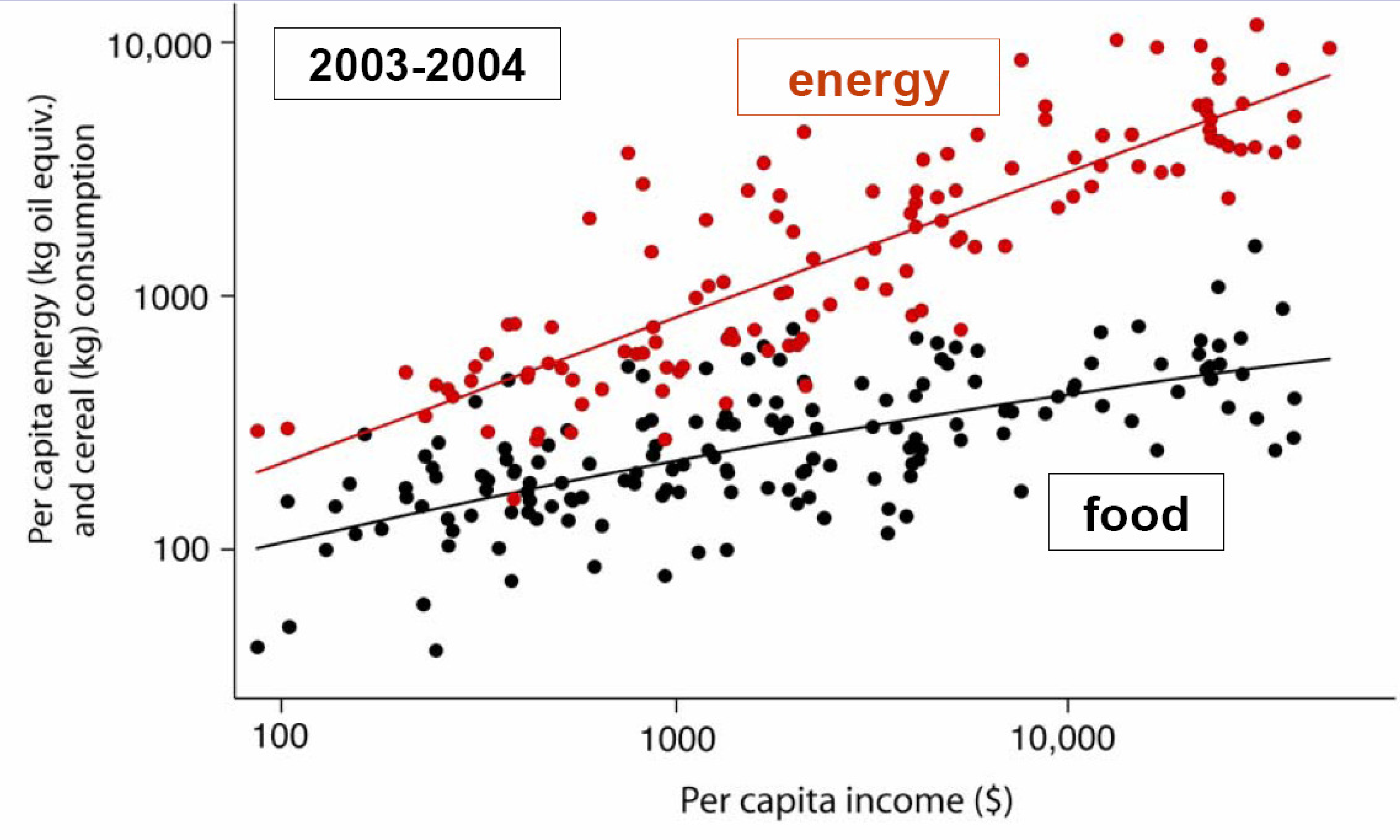
Food Security and Climate Change

- Direct connection between food security and GHG emissions
- If food production falls behind demand driven by population growth and economic development, a marked rise in food costs will motivate conversion of rainforest, wetlands, and grasslands to crop production
- Conversion of these carbon-rich ecosystems will accelerate GHG emissions, hence, ensuring global food security is fundamental to GHG mitigation strategies

Deforestation in *Chaco Forest, Argentina & Paraguay*

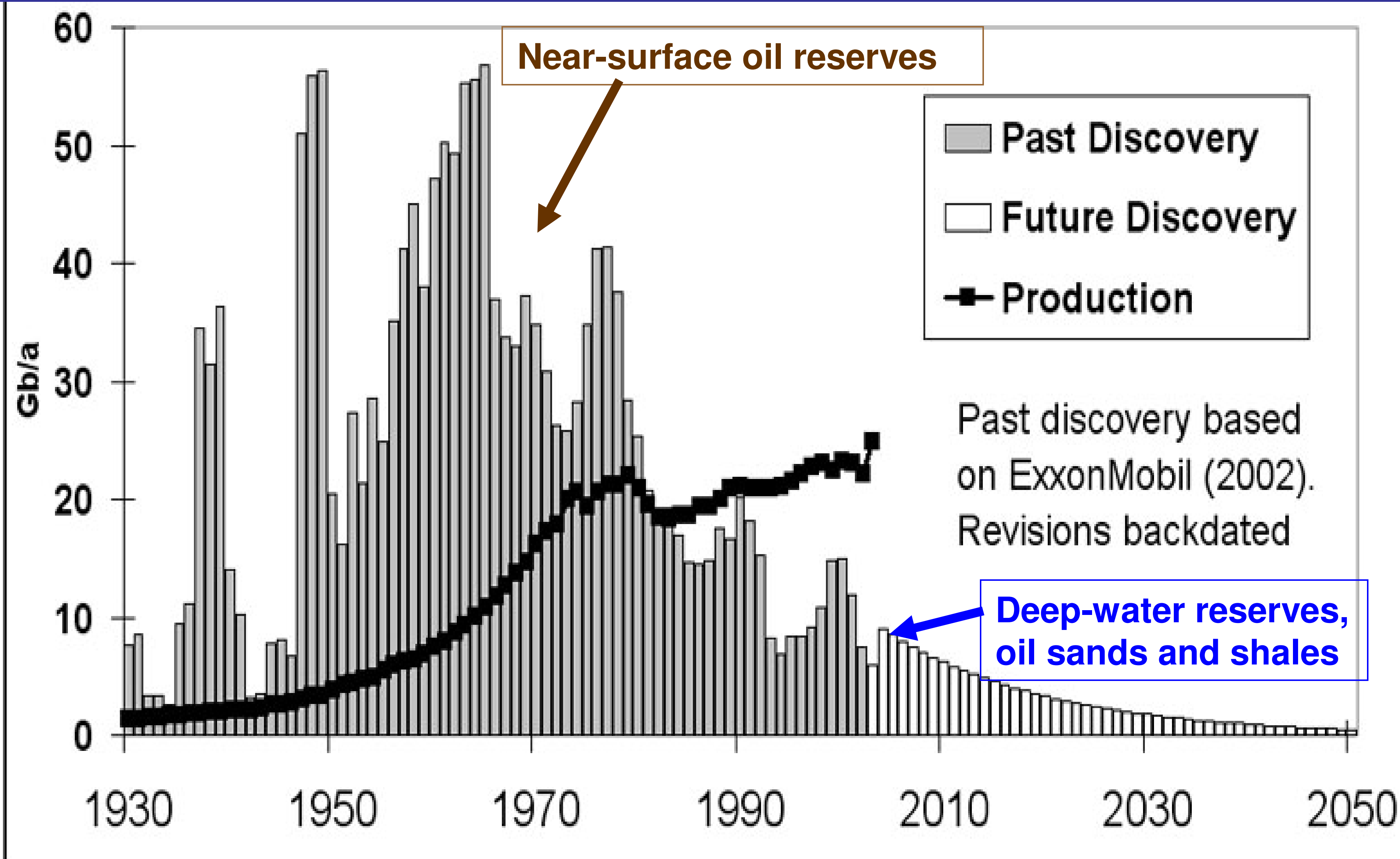
Photos: P. Grassini

The Challenge: Achieving food security for a larger population with higher income by 2050

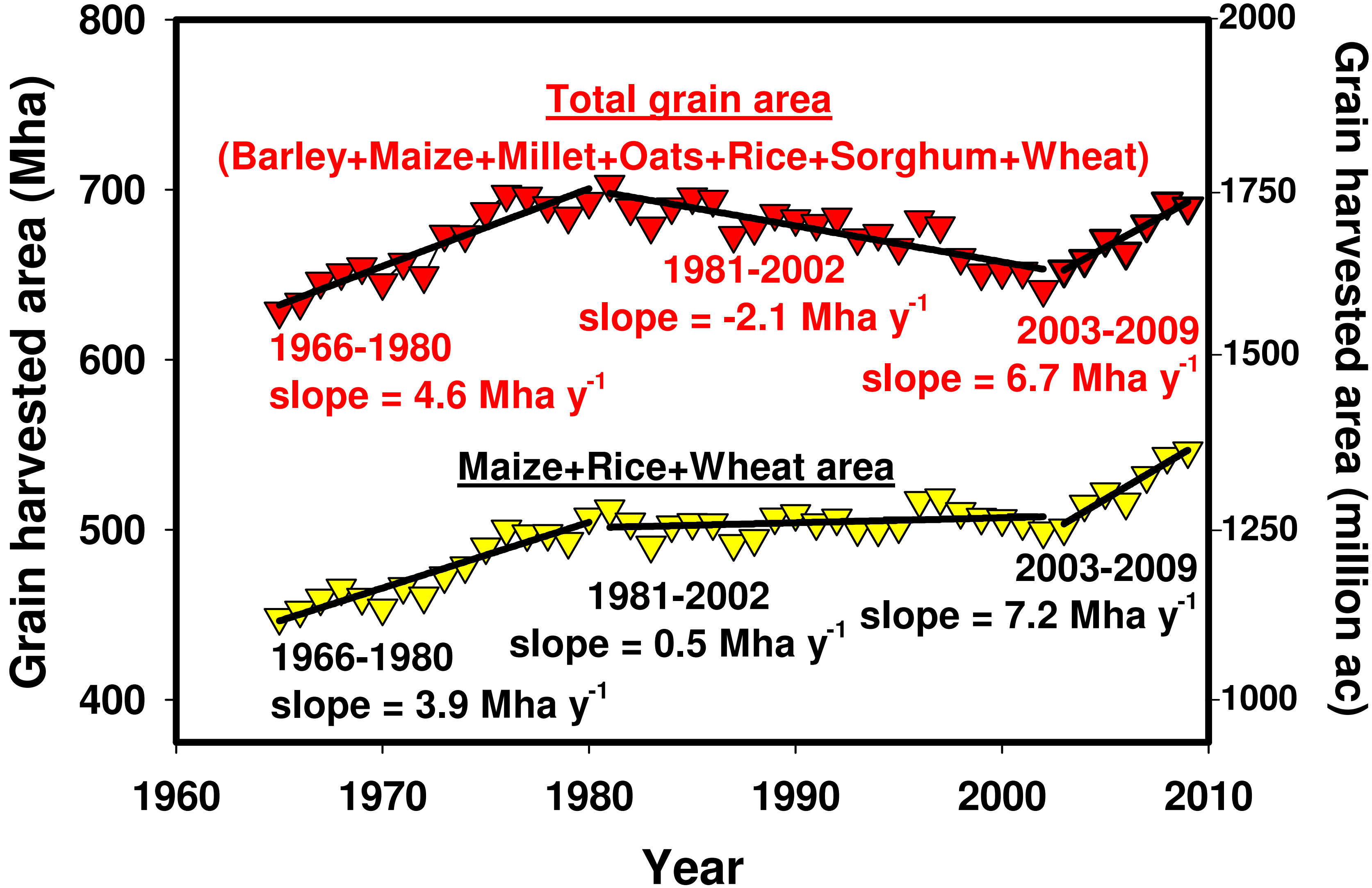


Naylor et al., 2007. *Environment* 40: 30-43. Energy and income data from World Bank development indicators; cereal consumption data from FAOSTAT.

Oil Production vs Oil Discovery



Global Cereal Area Trends, 1966-2009



Source: Cassman *et al.* (2010)

Urban-industrial expansion onto prime farmland at the periphery of Kunming (+6 million), the capital of Yunnan Province, China

Photo: KG Cassman

Mega Trends

- **Global population and income growth**
  - **9.2 billion by 2050 (+35%)**
- **Greater per capita energy and food consumption**
  - **+60% increase in cereal production needed by 2050: <u>1.5%</u> annual increase of today's average cereal yield (*= 1.25% compound annual rate of yield gain*)**
- **Limited scope for increasing cereal cropland area and/or irrigated cropland**
- **Increasing grain demand for biofuels and public concern for environmental quality, climate change, and biodiversity**

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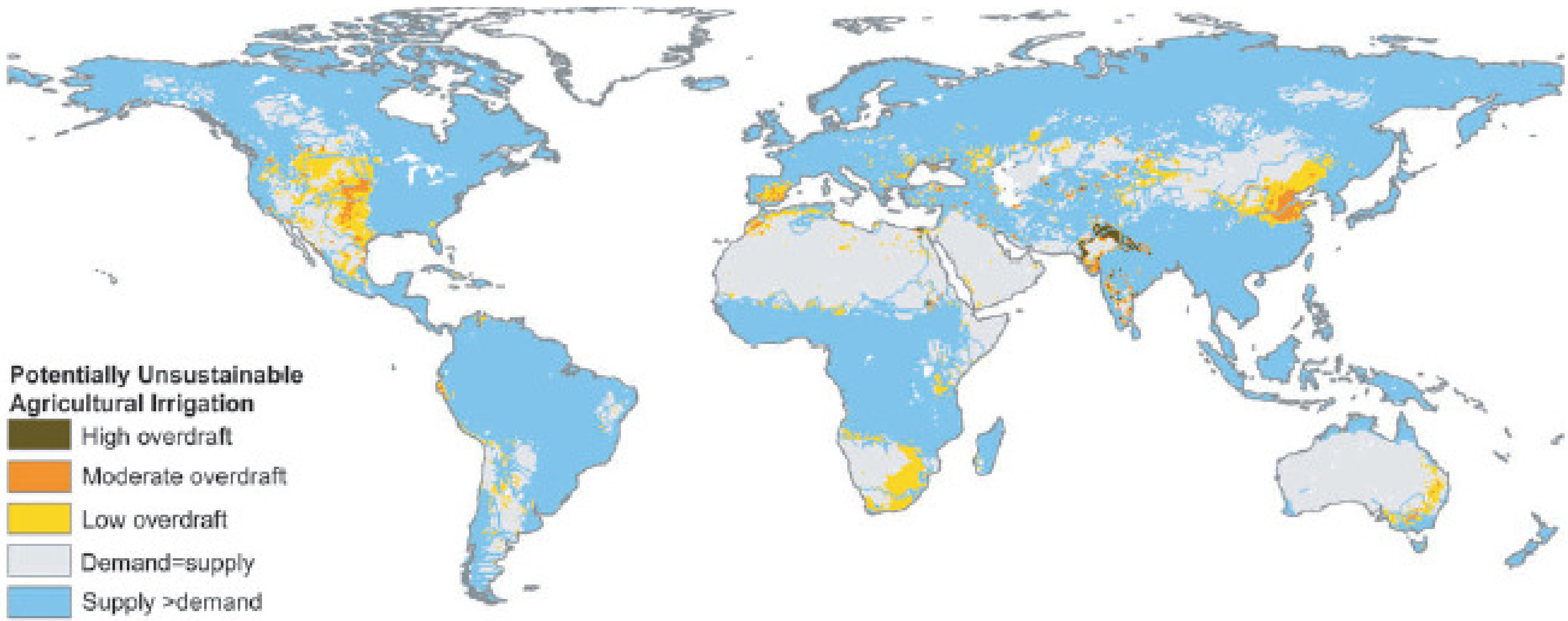
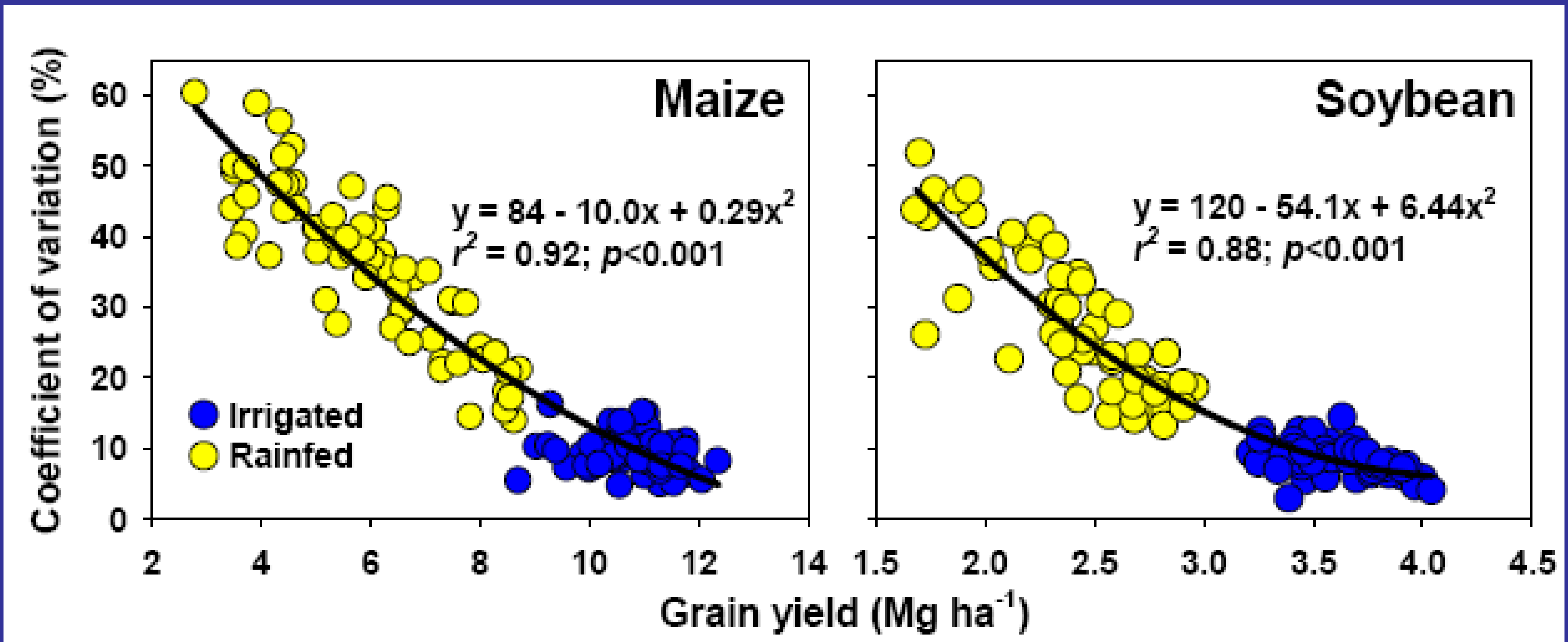
Decreasing water supply in all major irrigated areas



Yet, irrigated agriculture produces 40% of global food supply on just 18% of the cropped area.

Reliability of irrigated agriculture

2000-2009 average yields and coefficient of variation by county for maize and soybean in Nebraska (data from: USDA-NASS) (Source: Grassini & Cassman)



Assured water supply greatly increases yield and reduces year-to- year variation in yield. Irrigated agriculture attracted investment in livestock feeding operations, biofuel refineries, and manufacturing of irrigation equipment.

Mega Trends

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- Increasing grain demand for biofuels and public concern for environmental quality, climate change, and biodiversity amplify the challenge

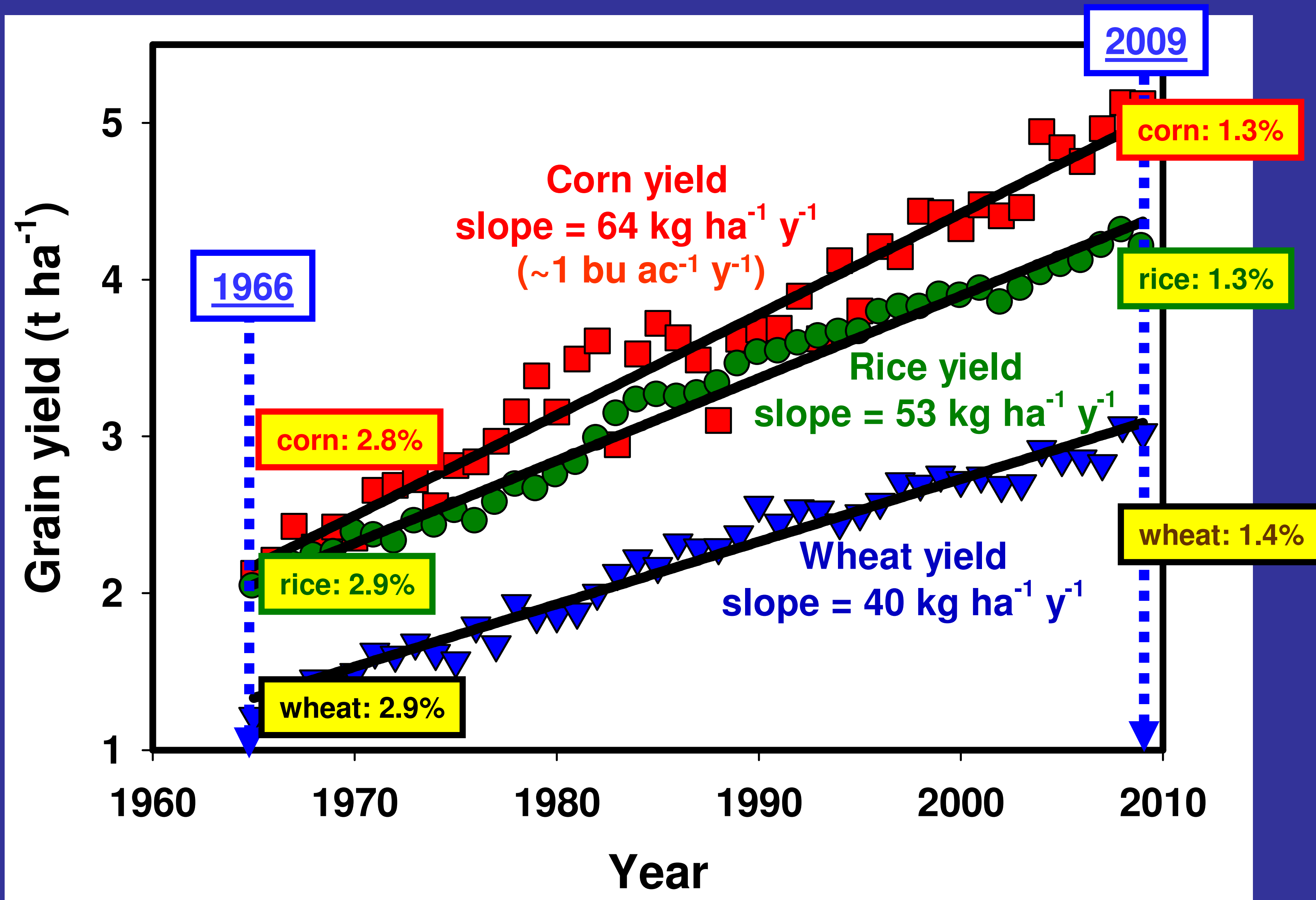
Impact of biofuels in food security

- **Biofuels compared to what in a world with changing climate?** Deep water petroleum? Oil sands? “Frac” natural gas? Coal? Nuclear Power?
- Use of cereal (maize, sorghum, wheat) and oilseed crops (soybean, oil palm) will increase due to current government mandates and rising cost of petroleum
- Use of perennial cellulosic crops (switchgrass, *Miscanthus*) will compete for crop land devoted to food crops—at least initially (first 5 billion gallons of second gen biofuels), due to higher development costs on marginal lands with low yield density
- Both will amplify need to accelerate rate of gain in crop yields on existing farm land while reducing agriculture’s environmental footprint

Clearing virgin rain forest in Brazil

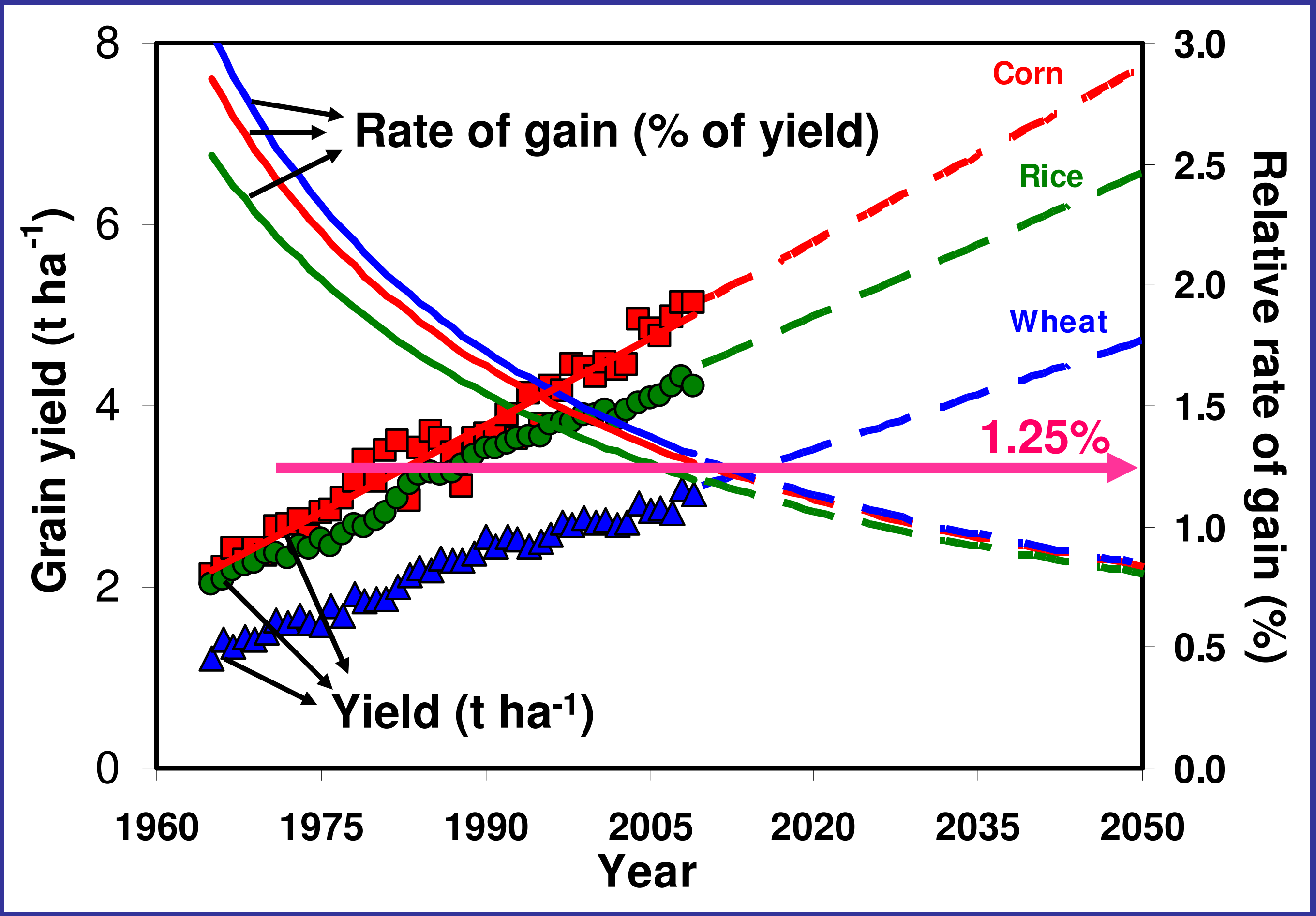
Photo: KG Cassman

Global Cereal Yield Trends, 1966-2009

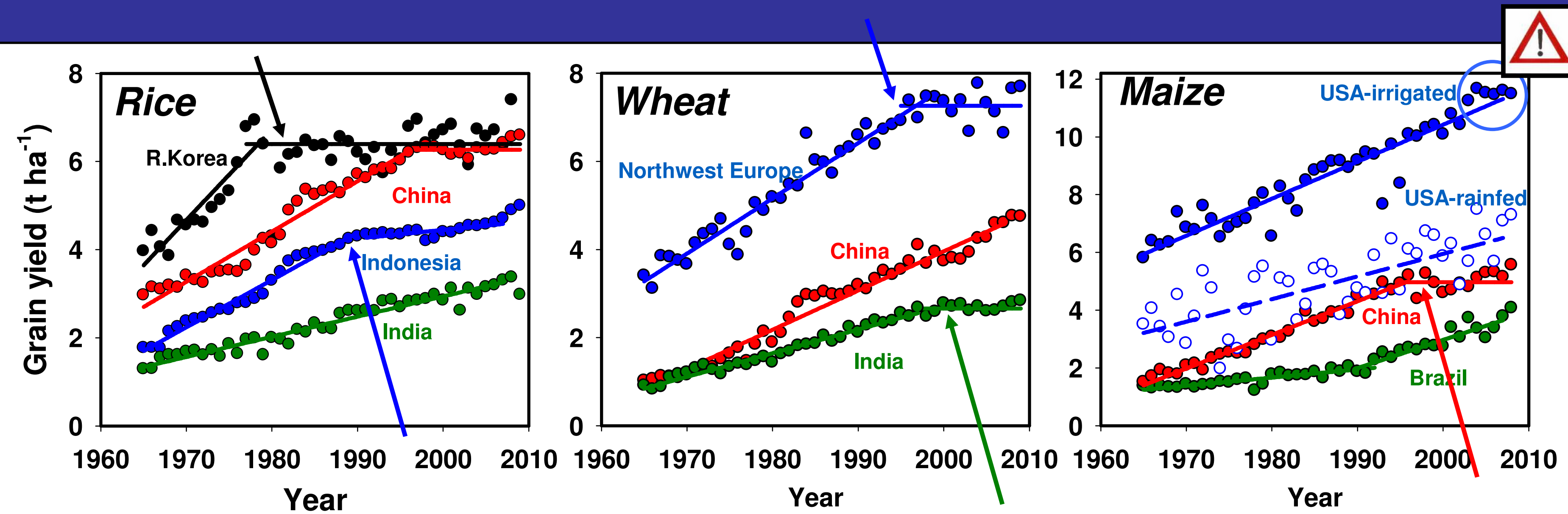


Source: Cassman et al., 2010

Tyranny of constant rate of yield gain: decreasing relative rate of gain



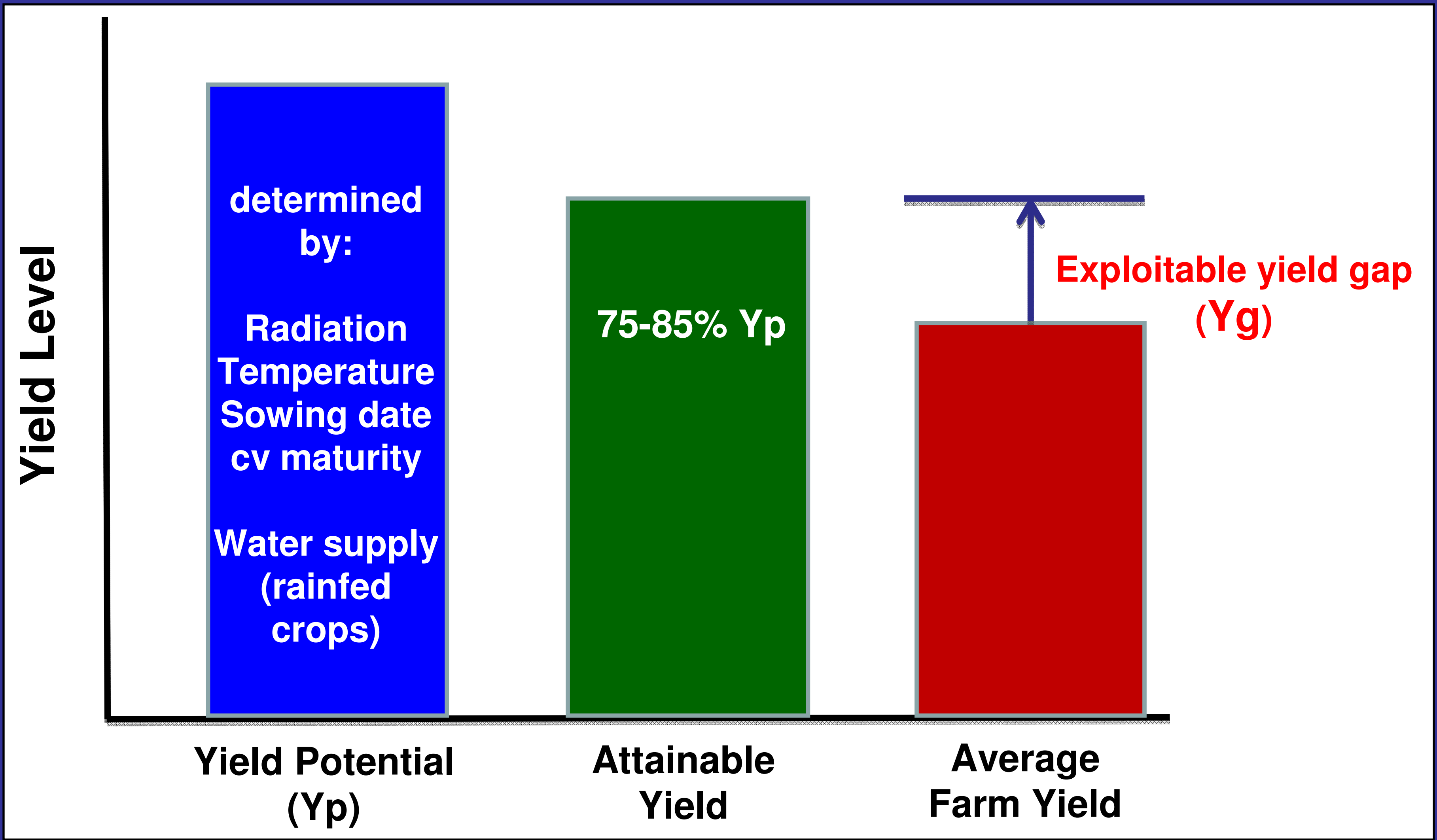
Also a concern are yield plateaus for several major crops in major cereal producing countries:



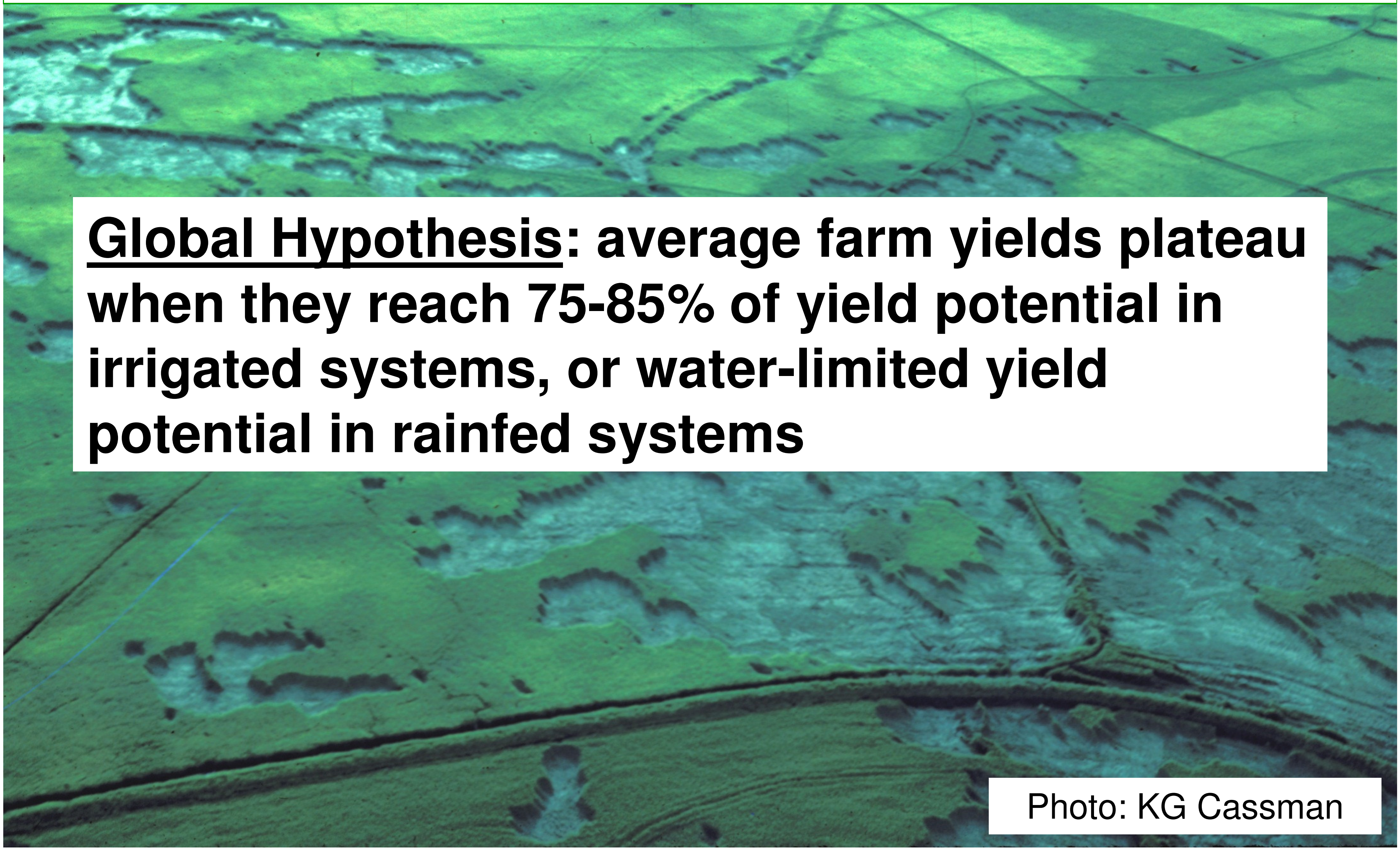
Note yield plateaus in Korea and China for rice, wheat in northwest Europe and India, and maize in China... and perhaps for irrigated maize in USA

Source: Cassman *et al.*, 2010

Yield Potential (Yp), Attainable Yield, and Exploitable Yield Gap



As on-farm yields approach yield potential, it becomes more difficult for farmers to sustain yield increases because further gains require elimination of small imperfections in the management of the cropping system which are usually risky and/or not economically viable

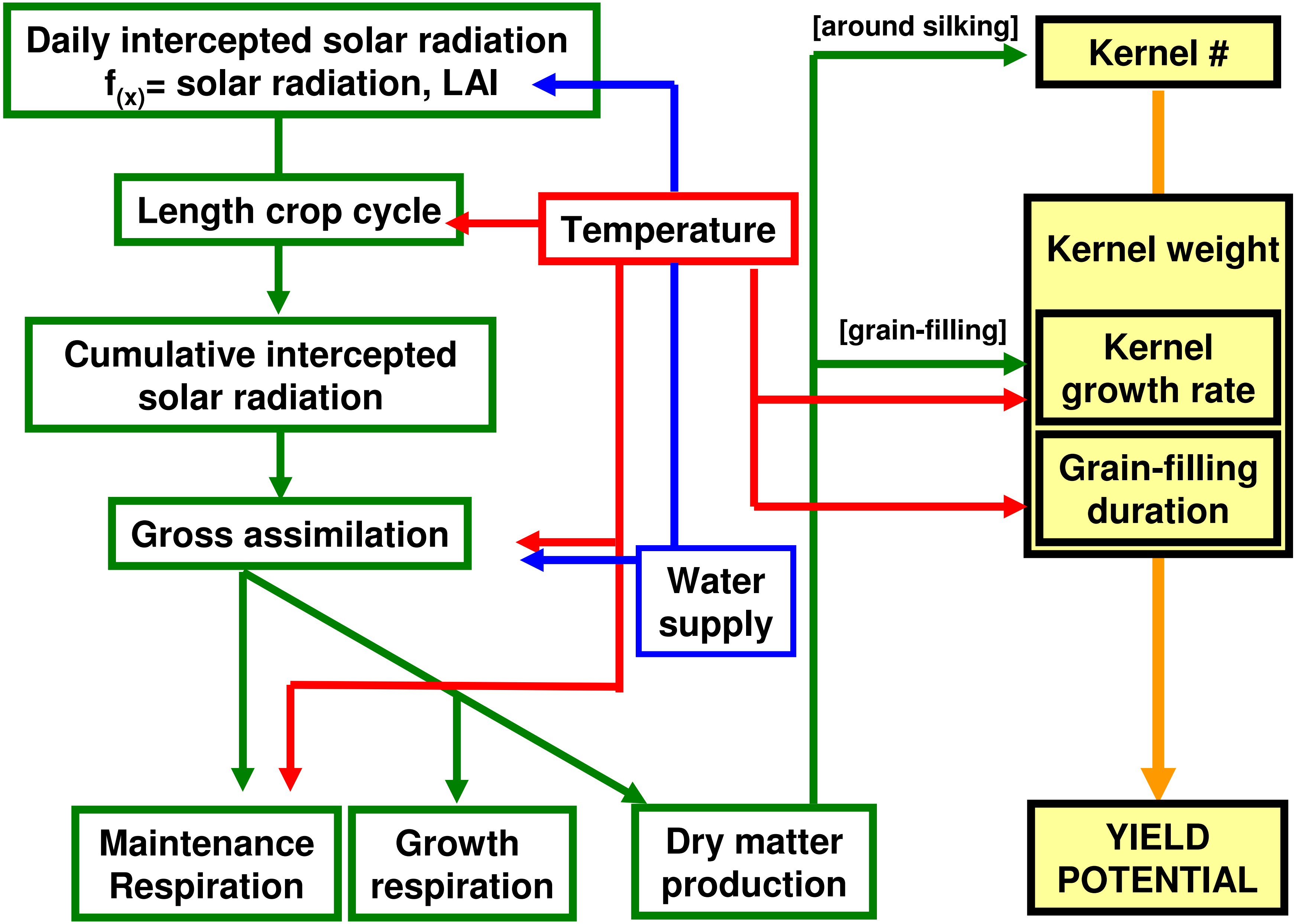


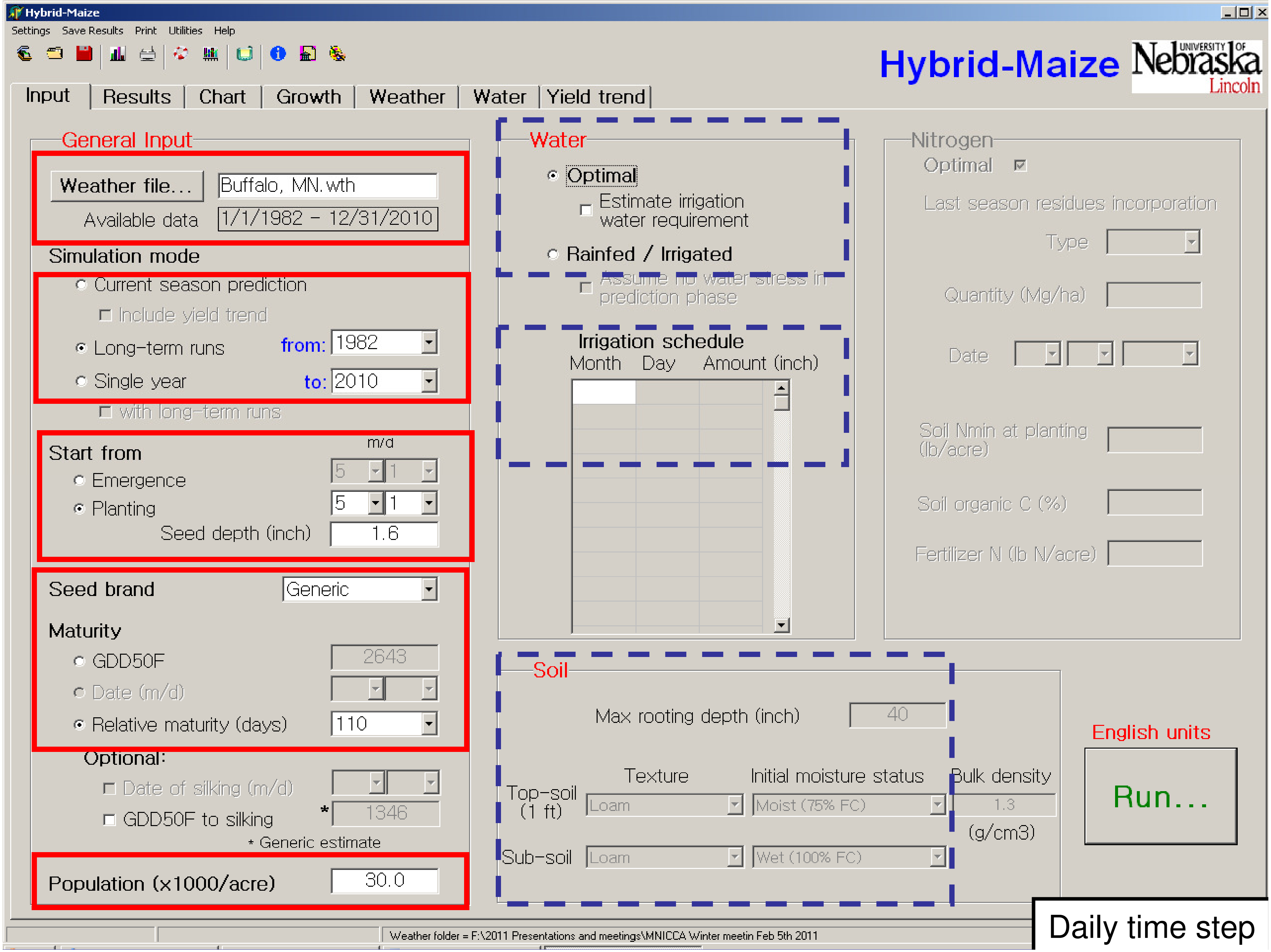
<u>Global Hypothesis</u>: average farm yields plateau when they reach 75-85% of yield potential in irrigated systems, or water-limited yield potential in rainfed systems

Photo: KG Cassman

Simulation models: tools to estimate yield potential

Crop models: tools to predict yield potential




Hybrid-Maize
Settings Save Results Print Utilities Help
Hybrid-Maize
Nebraska
Lincoln
Input
Results
Chart
Growth
Weather
Water
Yield trend
General Input
Weather file...
Buffalo, MN.wth
Available data
1/1/1982 - 12/31/2010
Simulation mode
Current season prediction
Include yield trend
Long-term runs
from: 1982
Single year
to: 2010
with long-term runs
Start from
m/d
Emergence
Planting
Seed depth (inch)
1.6
Seed brand
Generic
Maturity
GDD50F
2643
Date (m/d)
Relative maturity (days)
110
Optional:
Date of silking (m/d)
GDD50F to silking
1346
* Generic estimate
Population (x1000/acre)
30.0
Water
Optimal
Estimate irrigation water requirement
Rainfed / Irrigated
Assume no water stress in prediction phase
Irrigation schedule
Month Day Amount (inch)
Nitrogen
Optimal
Last season residues incorporation
Type
Quantity (Mg/ha)
Date
Soil Nmin at planting (lb/acre)
Soil organic C (%)
Fertilizer N (lb N/acre)
Soil
Max rooting depth (inch)
40
Texture
Initial moisture status
Bulk density
Top-soil (1 ft)
Loam
Moist (75% FC)
1.3
(g/cm3)
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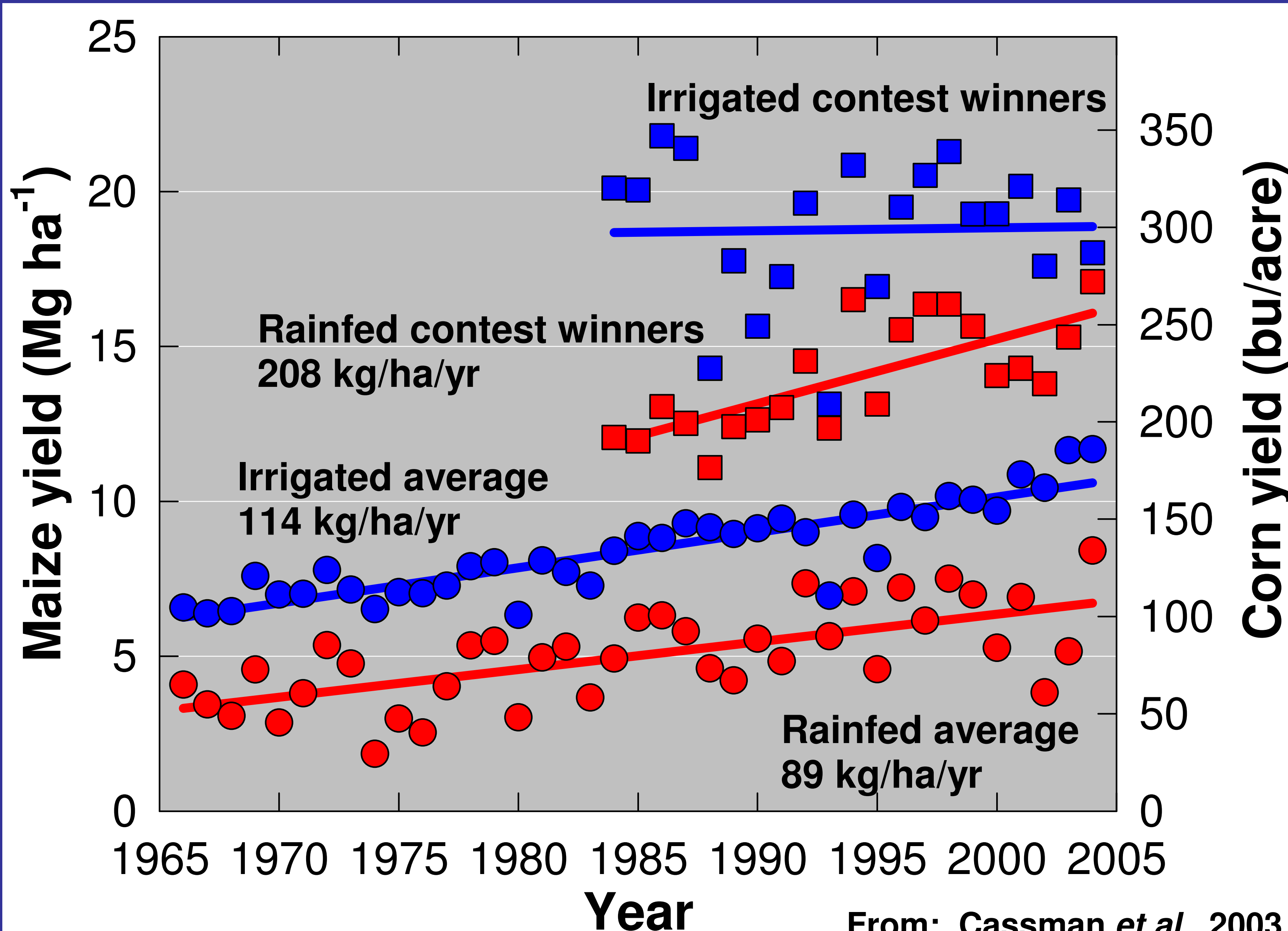
Loam
Wet (100% FC)
English units
Run...
Weather folder = F:\2011 Presentations and meetings\MNICCA Winter meetin Feb 5th 2011
Daily time step

Little change in yield potential of maize, rice, and wheat during last decades

- Graybosch, R.A., Peterson, C.J., 2010. Genetic improvement in winter wheat yields in the Great Plains of North America, 1959–2008. *Crop Sci.* 50:1882–1890
- Duvick D.N, Cassman K.G., 1999. Post-green- revolution trends in yield potential of temperate maize in the north-central United States. *Crop Sci.* 39:1622- 1630
- Peng, S., K.G. Cassman, S.S. Virmani, J. Sheehy, Khush, G.S., 1999. Yield potential trends of tropical rice since the release of IR8 and the challenge of increasing rice yield potential. *Crop Sci.* 39:1552-1559

Nebraska contest-winning and average yield trends

No increase in irrigated contest-winner yields since 1980s



From: Cassman *et al.*, 2003

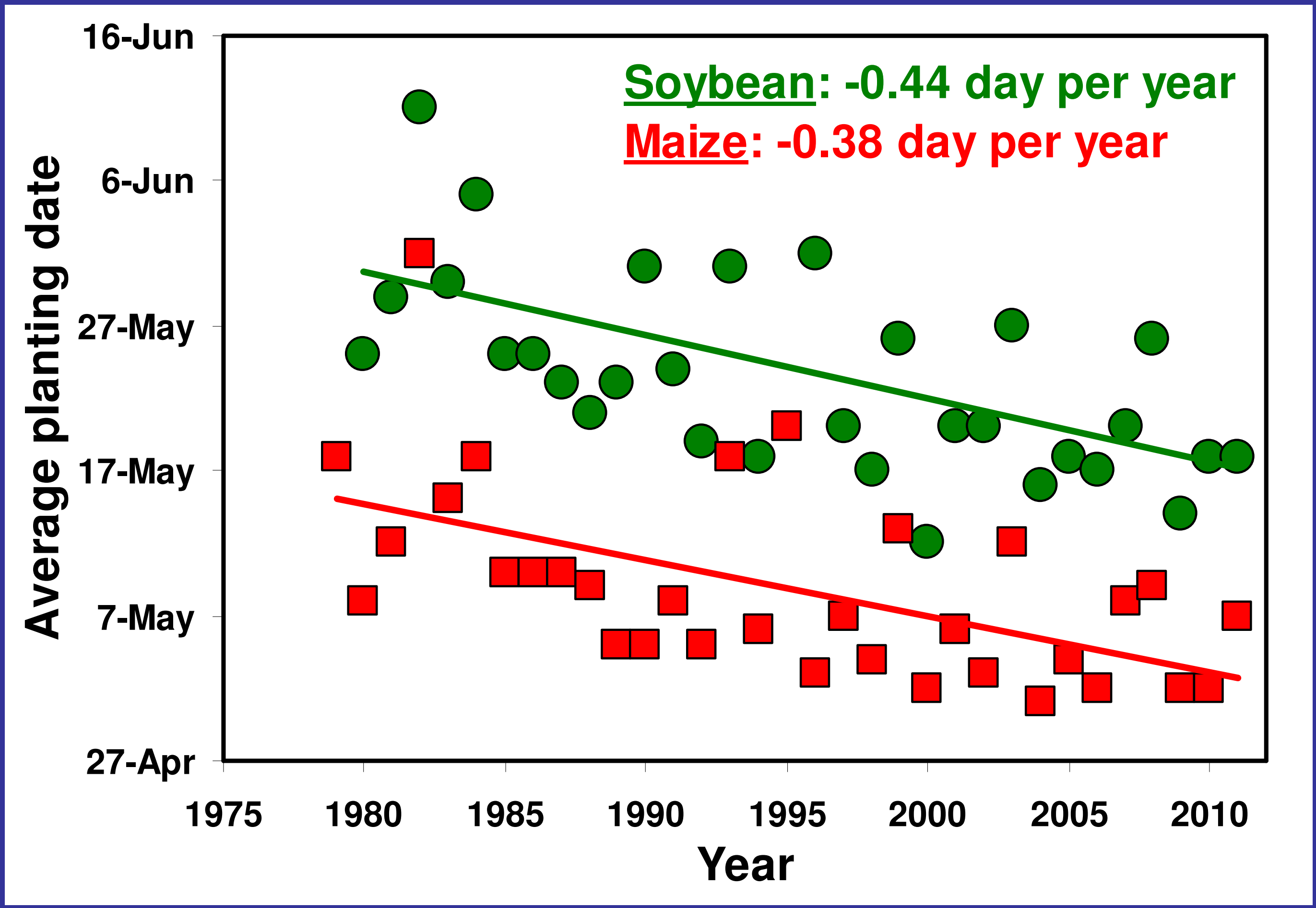
Bottom line on global trends

Business as usual will not meet projected global food demand in 2050 without large expansion of crop area:

- **Expansion of crop area limited by lack of good quality arable soils and concerns about loss of biodiversity**
- **Current rates of gain in crop yields not adequate to meet expected demand for food, feed, fiber, and fuel on existing crop land**
- **Little scope for increasing irrigated crop area**
- **Little increase in yield potential of cereals for the last decades; yield stagnation in some areas**
- **Recent evaluations of impact of climate change impact on crop yields suggest dire consequences for global food security**

Cropping systems are dynamic!

Trends in average planting date of soybean and corn in Nebraska **



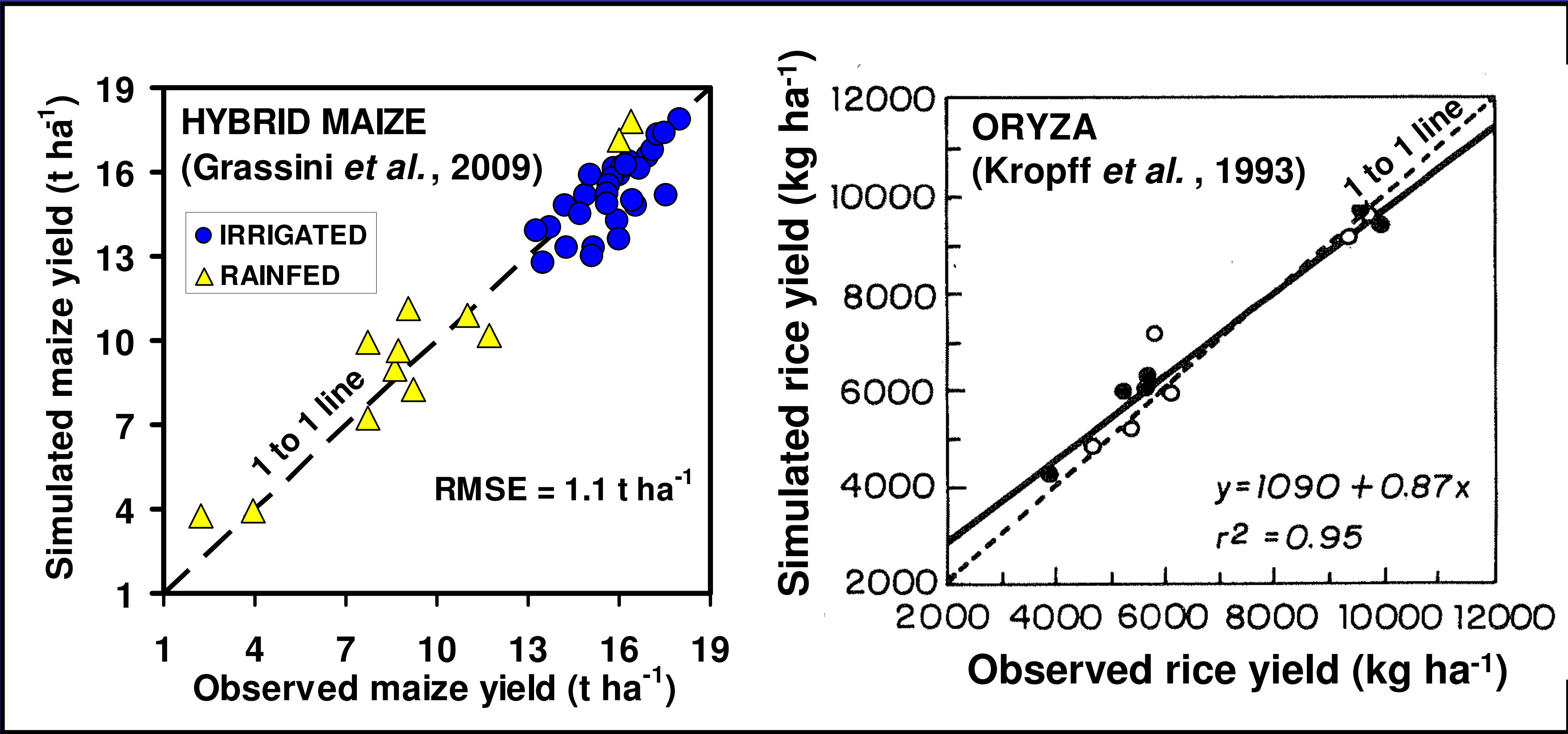
** Trends were significant at $p < 0.001$ ($R^2 = 0.31$). Data from USDA-NASS (1979-2011)

Implications for CC research

- Explicit emphasis on yield potential (Yp)
- Predictions should be made for crops, cultivars, and cropping systems most adapted to ‘future’ climate.
- Use of simulation models to reproduce genotype x environment x management interactions under changing climate
- Realistic simulations require robust models and high-quality data inputs

Validation of crop simulation models

Crop models must be able to reproduce yields of crops that approach Yp, across a wide range of environments, without need of on-site re-calibration.



Knowledge of crop management practices is required to obtain accurate Yp estimates

Small modifications in model inputs regarding management practices such as planting date or cultivar maturity can result in significant changes in Yp estimates

Example: Impact of modifying transplanting or maturity date by 7 days on simulated Yp of rice for 2 provinces in China

Province	Season	Base Yp	Transplant DOY		Maturity DOY		Transplant + Maturity DOY	
		(t/ha)	+7	-7	+7	-7	-7, +7	+7, -7
Sichuan	Single	9.2	-4%	3%	7%	-10%	10%	-13%
Anhui	Early	3.3	-11%	11%	15%	-15%	18%	-23%
Anhui	Middle	8.6	-5%	3%	13%	-14%	16%	-18%
Anhui	D.Seed	6.1	-15%	12%	-6%	-8%	22%	-24%
Anhui	Late	4.4	-10%	0%	4%	-10%	13%	-18%

Source: J. van Wart, UNL PhD Thesis

Impact of CC on food security

- Achieving food security during next decades will be a challenge with or without climate change.
- Overall, predicted climate to 2050 would not reduce global carrying capacity
- Climate change would certainly change production systems, productive regions, and export opportunities
- As a result, there would be winners and losers.

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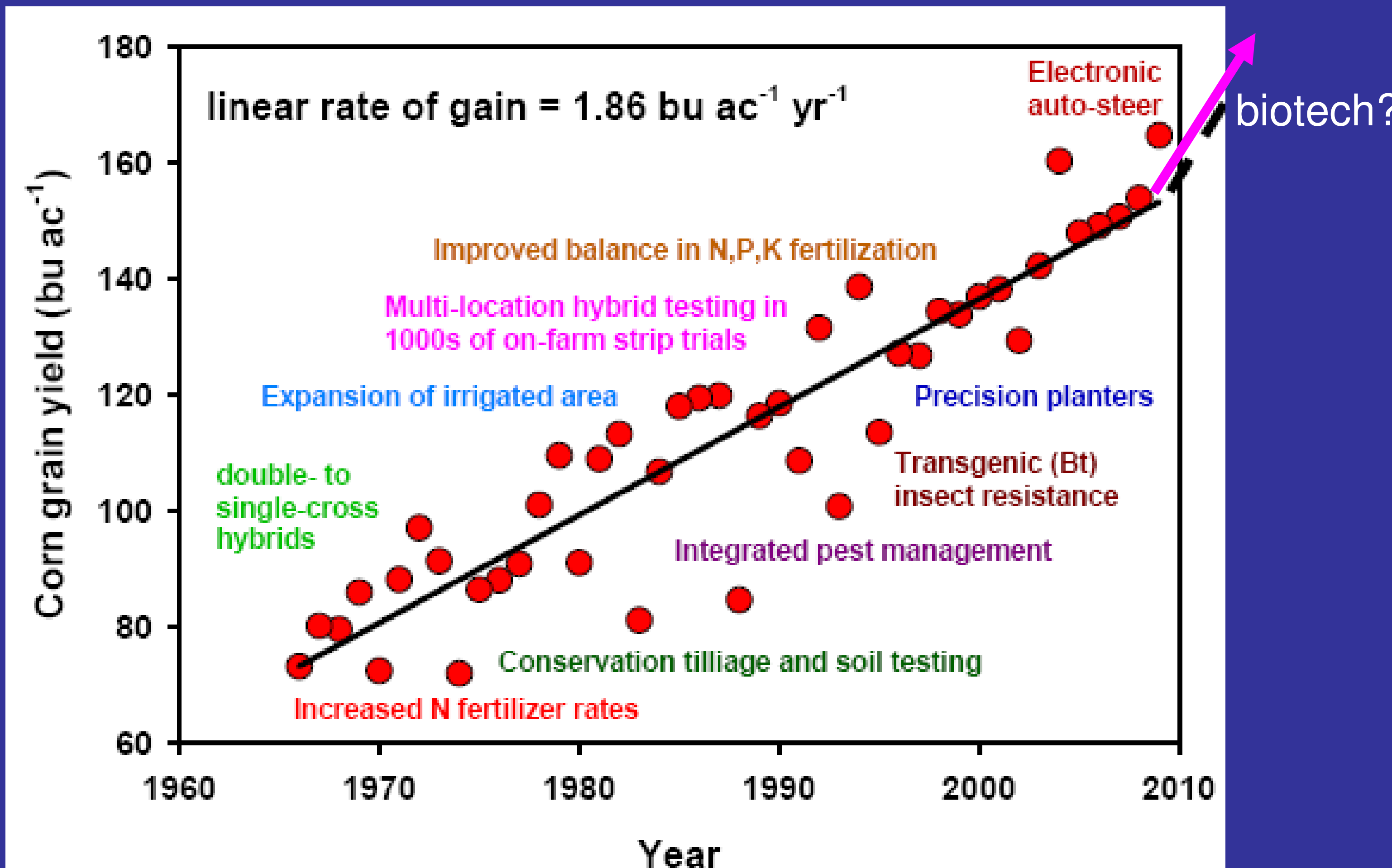
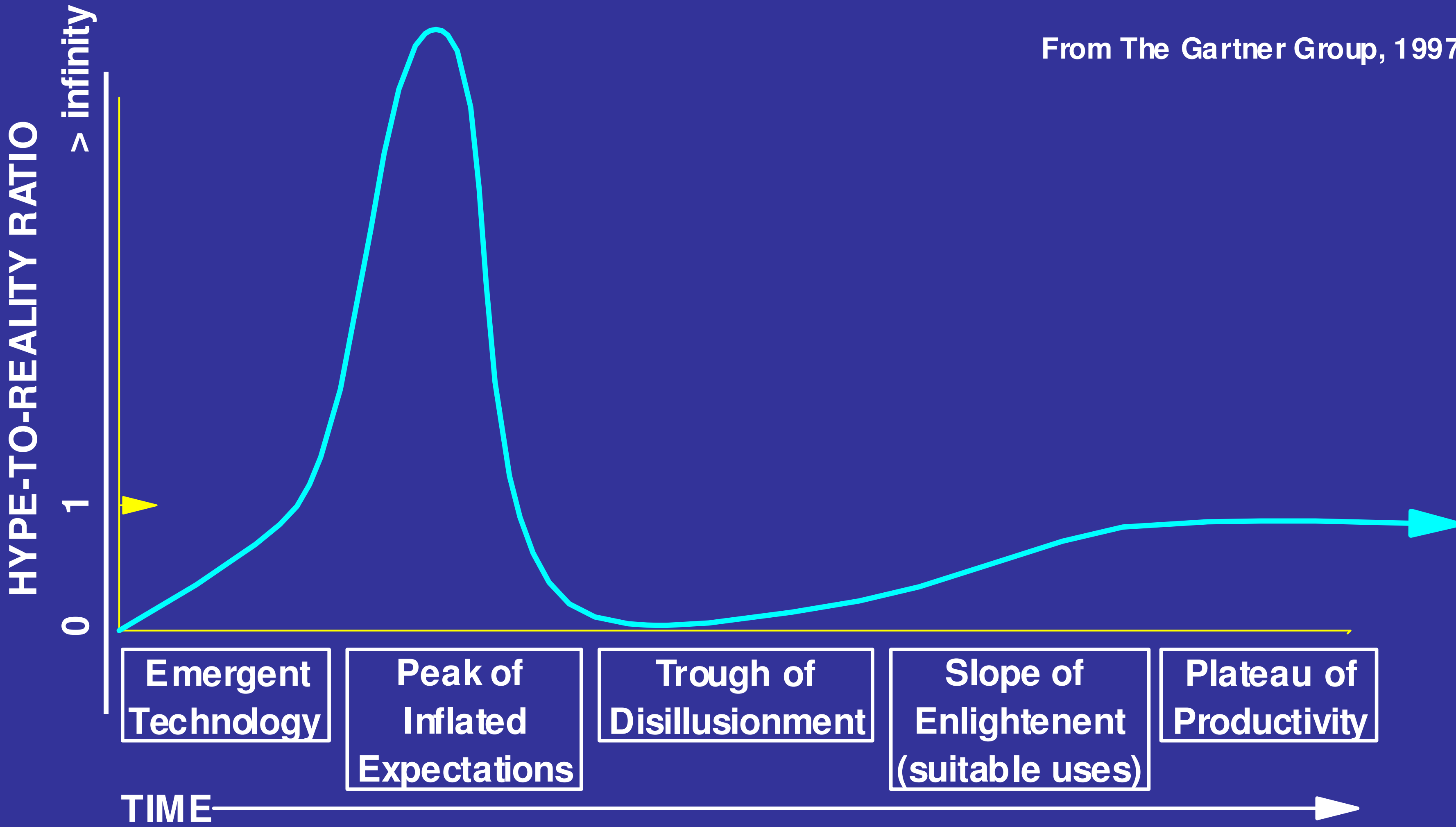
- **Little increase in yield potential of cereals for the last decades; yield stagnation in some areas**
- **What is scope for quantum leap in yields from biotechnology?**

USA corn yield trends, 1966-2009
(and underpinning science and technology support)



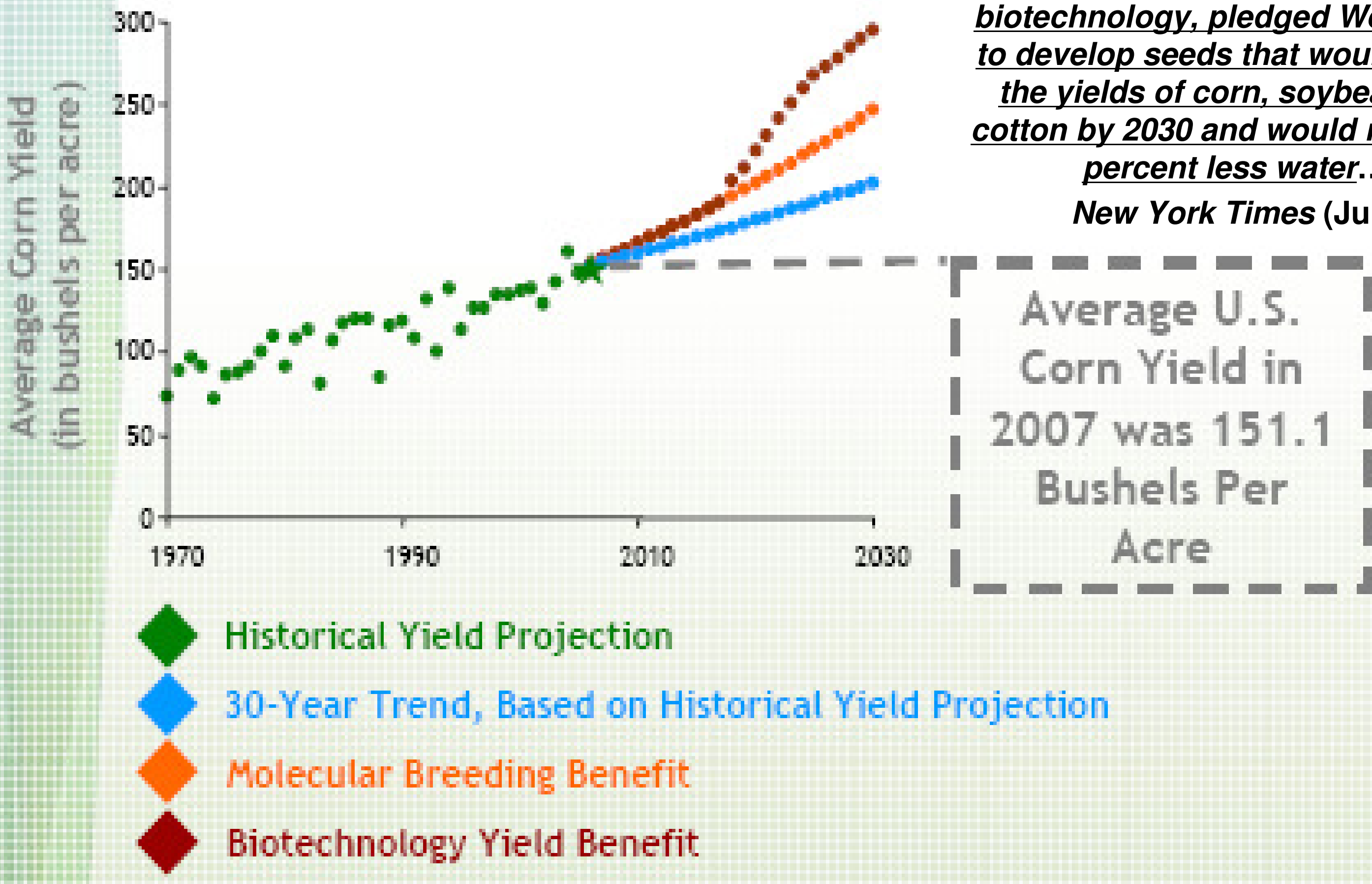
Modified from: Cassman *et al.*, 2006

Emerging Technologies - The Hype-To-Reality Ratio



Step-Changes in Corn Potential

From NCGA website, 8 May 2008:
http://www.ncga.com/PDFs/NCGA%20Presentation%20on%20Food%20and%20Fuel%205-7-08.pdf

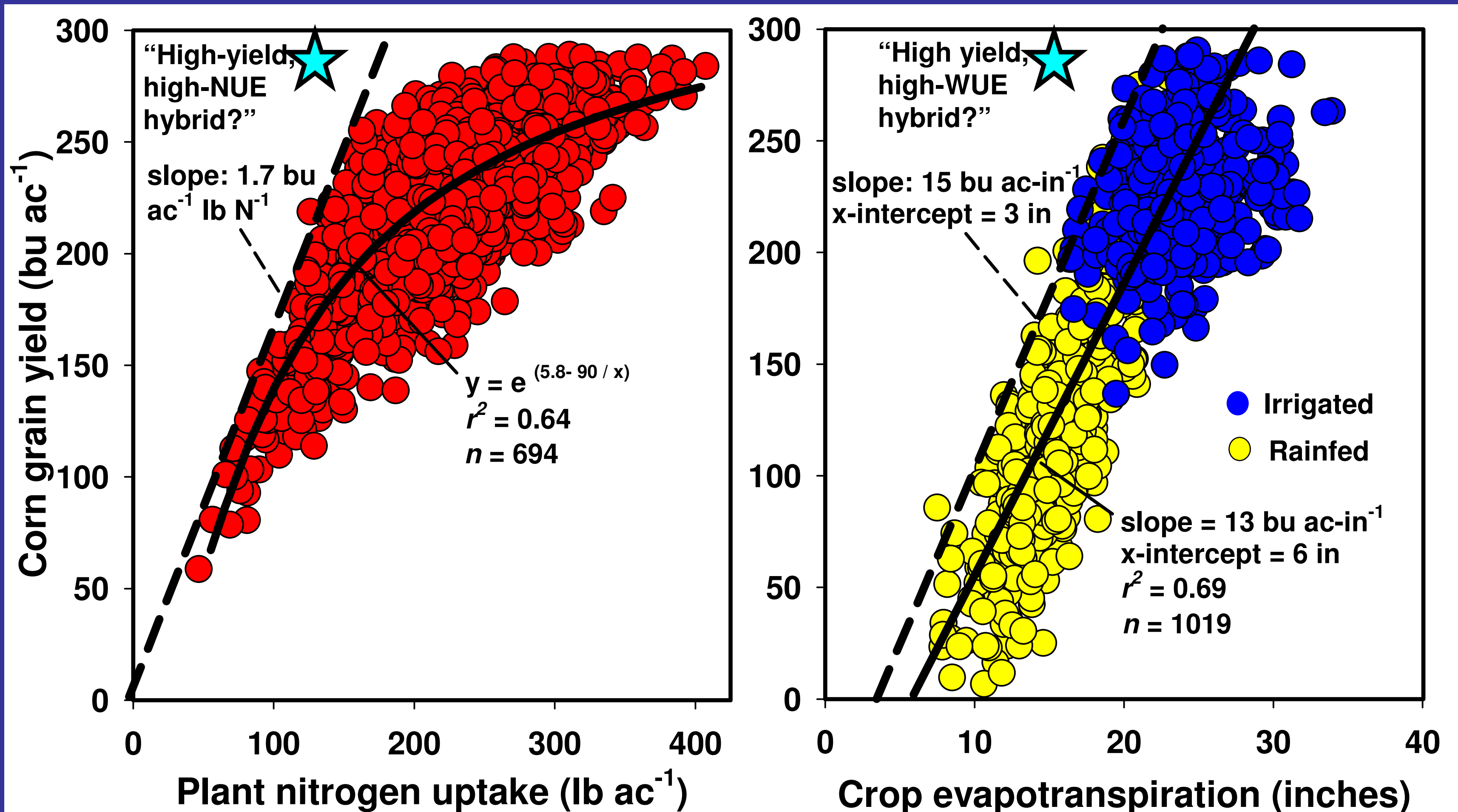


"***Monsanto, the leader in agricultural biotechnology, pledged Wednesday to develop seeds that would double the yields of corn, soybeans and cotton by 2030 and would require 30 percent less water…***"

New York Times **(June 5, 2008)**

Source: Monsanto

Hype vs. reality: fundamental relationships between corn yield, nutrient uptake, and evapotranspiration



Grassini *et el.* (2009), Setiyono *et al.* (2010)

High-yield crops have relatively large N and water requirements!

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Meeting future demand for food and energy, without massive land use conversion, requires <u>ecological intensification</u> of existing cropland area, that is, to close the gap between average farmer's yield and yield potential while minimizing the environmental impact

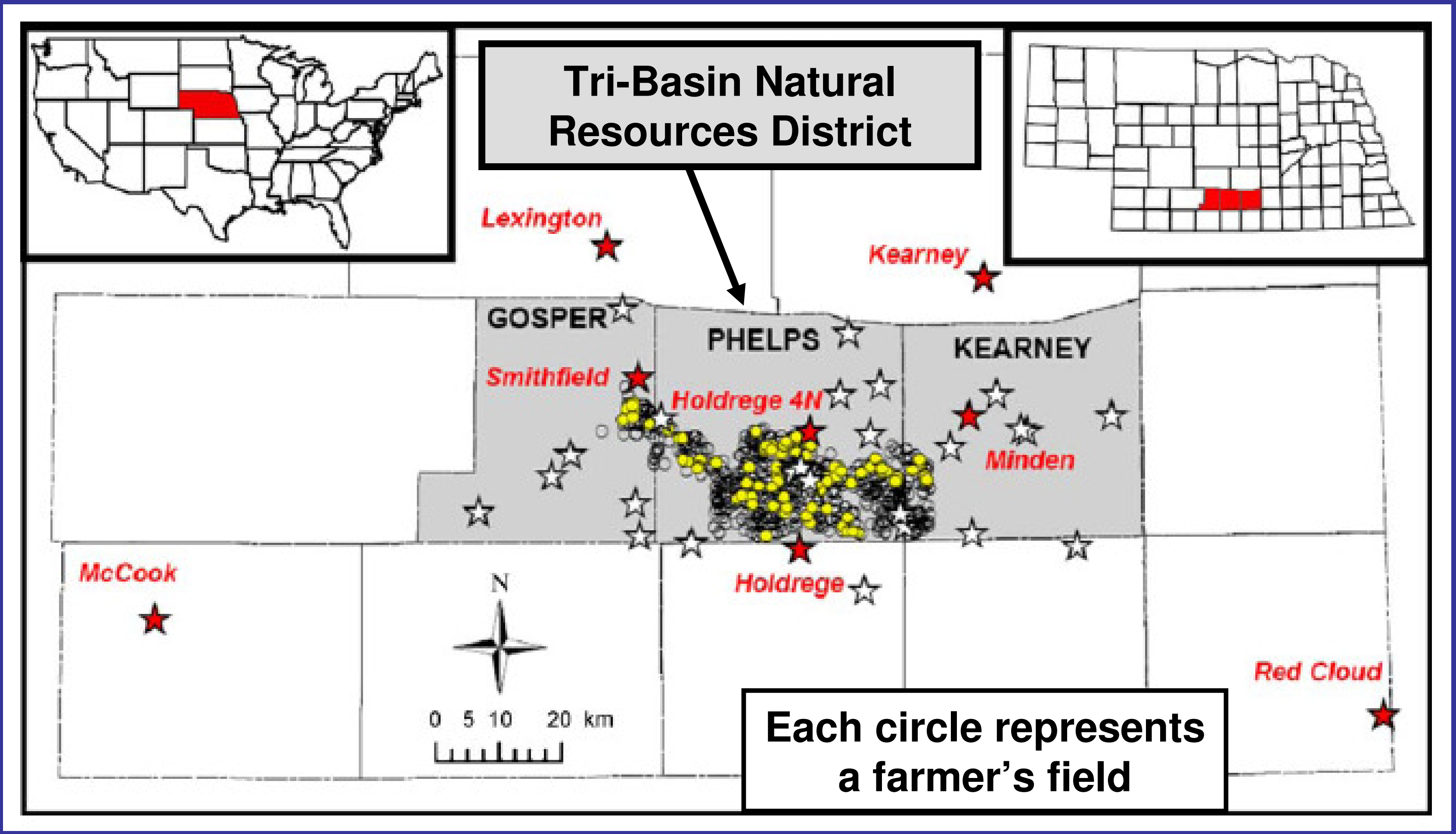
Photo: Lori Potter

Need for Ecological Intensification

- **Development of high-yield crop production systems that protect soil and environmental quality and conserve natural resources**
- **Characteristics of EI systems:**
  - **Yields that reach 80-85% of genetic yield potential**
  - **70-80% N fertilizer uptake efficiency (vs 30-40% now)**
  - **Improve soil quality (nutrient stocks, SOM)**
  - **Integrated pest management (IPM)**
  - **Contribute to net reduction in greenhouse gases**
  - **Have a large net positive energy balance**
  - **In irrigated systems: 90-95% water productivity**

Is Ecological Intensification an Oxymoron?

On-farm research: 777 irrigated corn fields in Nebraska during 2005-2007



Source: Grassini *et el.* (2011)

Corn yield and management in irrigated maize

	2005	2006	2007	Average
Grain yield (bu ac^{-1}) †	218	199	205	207
Applied irrigation (in) †	14	10	8	11
N rate (lb ac^{-1}) †	161	163	160	161
Sowing date ¶	24 Apr	25 Apr	3 May	27 Apr
Hybrid maturity (d) ¶	113	113	113	113
Seeding rate (ac^{-1}) ¶	30k	30k	30k	30k

† Based on 777 site-years (2005-2007)
¶ based on a subset of 123 site-years

Source: Grassini *et el.* (2011)

Mean (2005-2007) U.S. corn yield = 149 bu ac^{-1}; World-average = 75 bu ac^{-1}

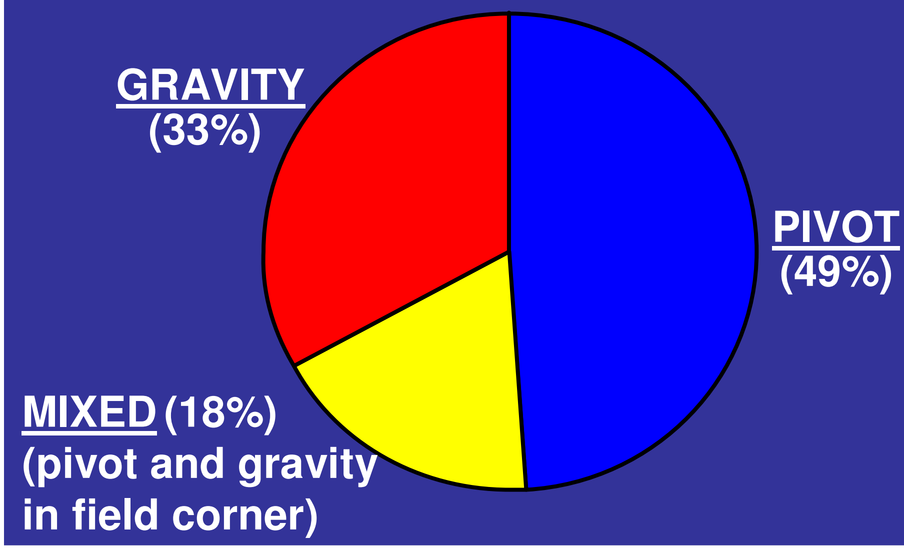
Tri-Basin NRD: production costs no-tilled center-pivot irrigated corn after soybean

	Cost ($/ac)	% total variable costs
Irrigation pumping ¶	120	27
Fertilizer (N, P)	100	22
Hybrid seed	85	19
Diesel use for tillage operations	80	18
Herbicide	40	9
Grain drying	25	6
Insecticide	2	<1

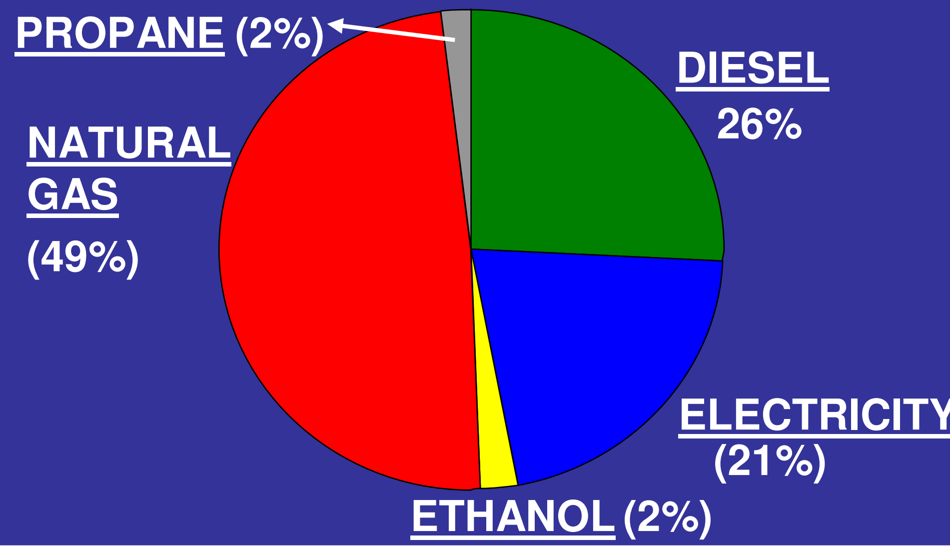
Source: Grassini *et el.* (2011)

Tri-Basin NRD: irrigation, rotation, and tillage

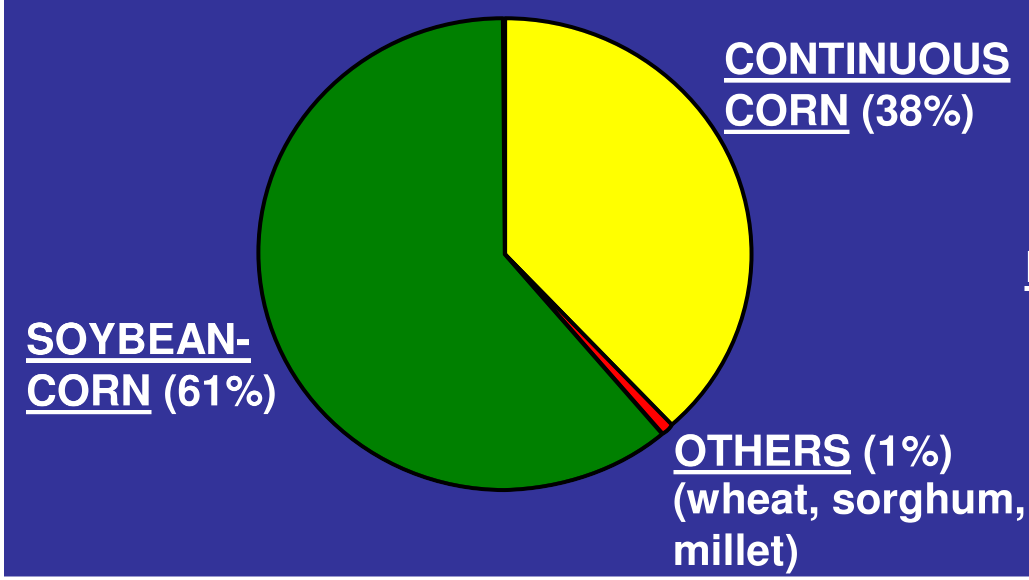
Irrigation system (*n* = 777)



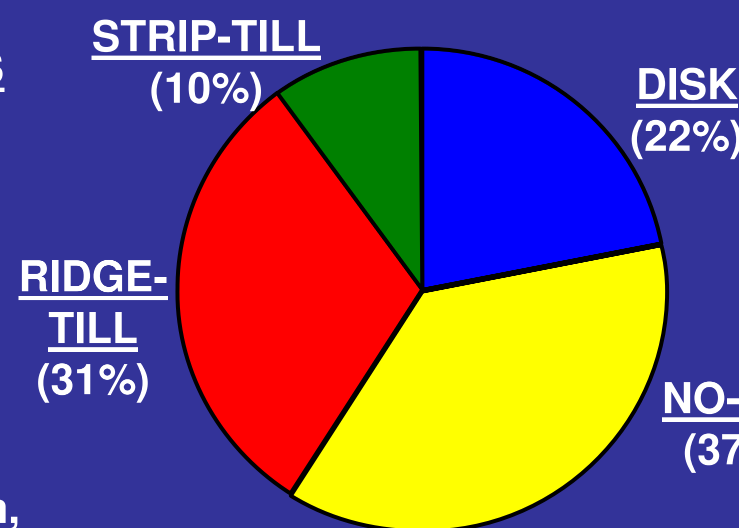
Energy source for pumping (*n* = 777)



Crop rotation (*n* = 777)



Tillage system (*n* = 123)



Source: Grassini *et el.* (2011)

Grain yield and input-use efficiency in maize production in Nebraska ¶

Source: Grassini *et al.* (submitted to Environmental Science & Technology))

Crop-system variable	Rainfed	Irrigated	Difference (%)¶
Grain yield (bu ac^{-1})	94	207	+124
Yield inter-annual variation (CV)	23%	3%	
Applied N fertilizer (lb N ac^{-1})	98	163	+66
N-fertilizer efficiency (bu lb^{-1} N)	1.0	1.3	+32
Total water supply (in) †	26	36	+40
Water productivity (bu ac-in^{-1})	3.6	5.8	+59

¶ Relative to the rainfed maize value. Based on data from 2005-2007

† Includes plant-available soil water at planting, in-season rainfall, and applied irrigation.

Despite higher applied inputs, grain yield and nitrogen- and water-use efficiencies were higher (and more stable) in irrigated corn

Energy balance and greenhouse gas (GHG) emissions from maize production in Nebraska

Source: Grassini *et el.* (submitted to Environmental Science & Technology))

Crop-system variable	Rainfed	Irrigated	Difference ¶
Energy input (GJ ha^{-1})	10.8	30.0	+178%
Net energy yield (grain energy minus fossil-fuel energy)	74	159	+115%
Energy net ratio (grain energy : fossil-fuel energy)	7.9	6.6	-16%
GHG emissions (kg CO_2e ha^{-1})†	2289	3049	+33%
GHG intensity (kg CO_2e t^{-1})‡	388	231	-40%

¶ Relative to rainfed maize values. Based on data from 2005-2007.

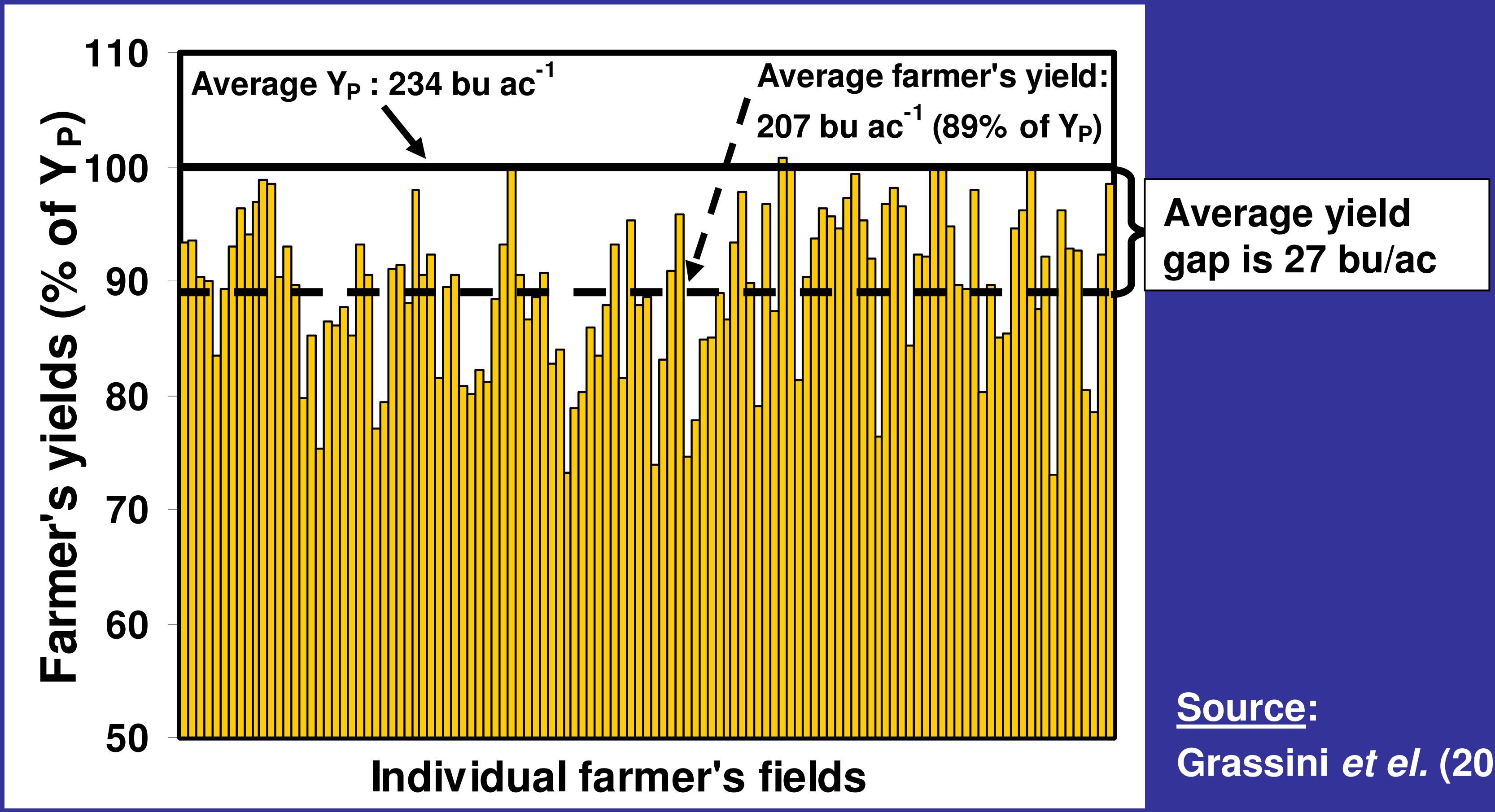
† Includes emissions of CO_2, N_2O, and CH_4 adjusted for CO_2 warming equivalent. Soil N_2O estimated by the N-surplus method of Van Groenigen *et al.* (2010).

‡ GHG emissions per metric ton of grain production

High-yield irrigated corn achieve large positive energy balance with low GHG emission intensity

How do field yields compare to their potential yield?

Farmer's yields expressed as percentage of simulated yield potential (Y_P). Each bar corresponds to a corn field from a subset of 123 fields in the Tri-Basin NRD. Yield potential was simulated for each field based on actual weather and management

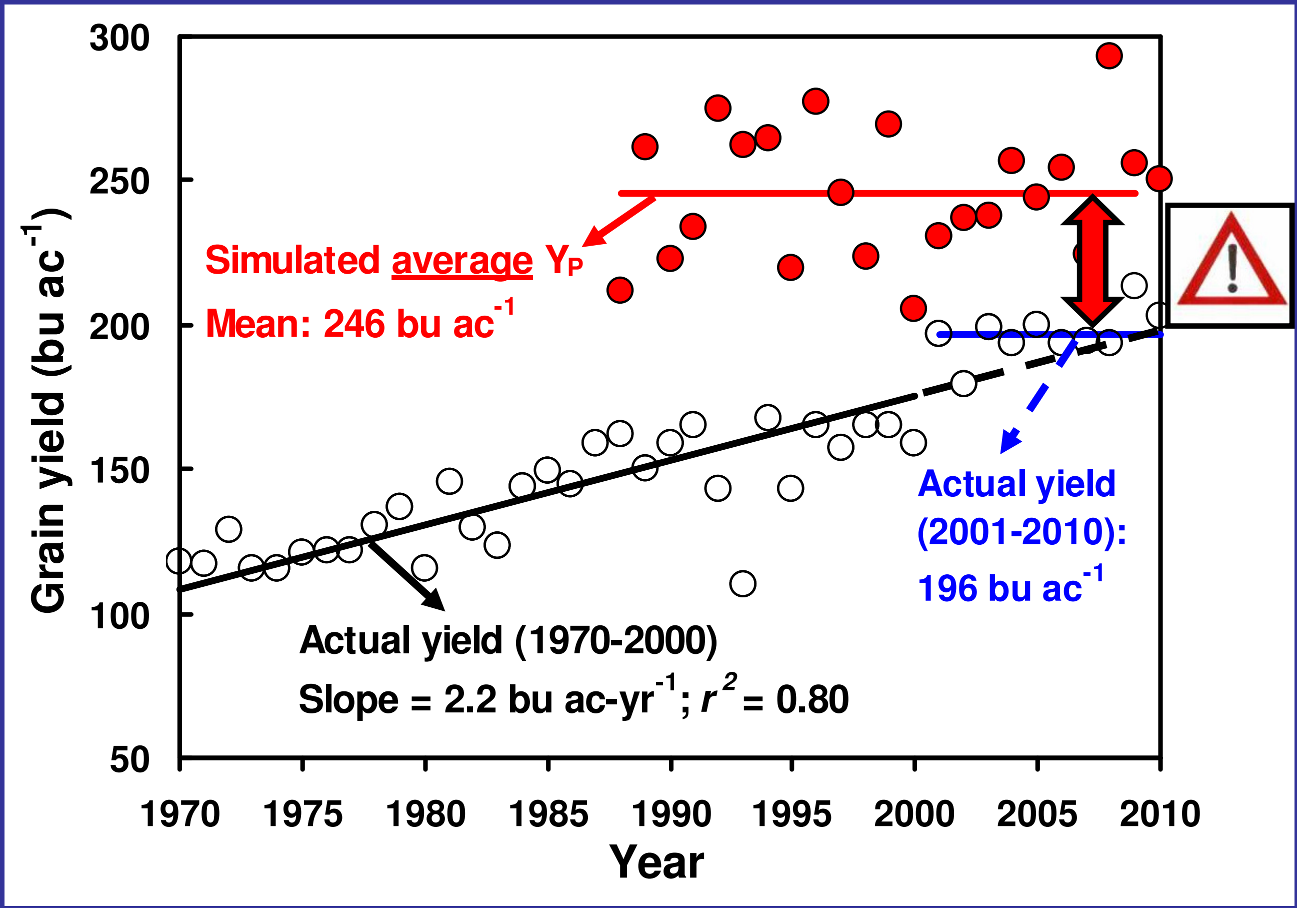


Source: Grassini *et el.* (2011)

Farmer's yields were, on average, 89% of yield potential

Actual irrigated corn yield* and yield-potential** trends: Are we approaching the ceiling?

** Average Tri-Basin NRD irrigated yields derived from NASS (1970-2010); ** Simulated corn yield-potential based on farmer-reported management practices in Tri-Basin NRD*



Last 10-y yield = 196 bu ac-1 (80% of yield potential)

Significant increases on actual yields are unlikely without changes on the yield-potential ceiling

Source: Grassini *et al.* (2011)

CRITICAL need for Global Yield Potential and Yield Gap Atlas

- **Robust, transparent, strong scientific foundation**
- **Interpret historical yield trends and yield plateaus (predict yield plateaus)**
- **Estimate global food production capacity on existing farm land, or additional land requirements due to land use change under different policy scenarios (e.g. impact of biofuel policies on direct and indirect land use change)**
- **Prioritize research and inform agricultural policies to ensure global food security**
  - **Identify areas with largest unexploited yield gaps, identify constraints, close yield gaps through ecological intensification**

University of Nebraska Lincoln | Nebraska Center for Energy Sciences Research

Water for Food — A Global Institute at the University of Nebraska

Wageningen Universiteit — Wageningen UR

Global Yield Gap and Water Productivity Atlas

Ken Cassman, Patricio Grassini, Justin van Wart
(University of Nebraska-Lincoln)

Martin van Ittersum
(Wageningen University)

--An international collaboration to develop a Global Yield Potential, Yield Gap, and Water Productivity Atlas within the next three years

--International Workshop to initiate the project: 31 Aug – 2 Sept, Chinese Agricultural University, Beijing (funding support from CAU and UNL-WFI, and collaboration with Wageningen Univ.)

Objective

To develop an agronomically robust and transparent approach, applied in a consistent manner throughout the world, with state-of-the-art geospatial databases on soil, weather and crop management, to estimate yield potential (Yp) and yield gaps of all major food crops, using the most appropriate crop simulation models.

Previous Estimates of Yield Potential (Yp)

- Used generic, non-species specific crop growth parameters (Kassam, 1979; Williams *et al.*, 1989) and/or monthly averages and simulated or derived climate data (Fischer *et al.*, 2002; Foley *et al.*, 1996), rather than “real” climate data
  - **Too coarse**
- Were not explicit with regard to data sources, methods, and underpinning assumptions
  - **Cannot be validated by others (not transparent!)**
- Used simulation models calibrated to local, generic, or “average” crop performance (Bondeau *et al.*, 2007)
  - **Simulation models must be rigorously validated against field studies that sought to achieve yield potential (Yp)**
- Did not account for cropping systems
  - **Yp must be simulated within constraints of current cropping patterns and management; farmers optimize systems rather than a single crop**

So, how to determine yield limits (YL)?

(Ph.D. thesis, Justin van Wart, Univ. of Nebraska)

1. **Geospatial distribution of crop area** (*e.g.*, Portmann *et al.*, 2010)

↓

2. **Select reference weather stations (RWS) to cover 50% of crop area**
   - Requires reliable data, 20-yr time series, quality control measures
   - Daily solar radiation, Tmax, Tmin, rainfall, etc. as required by the model

↓

3. **Soil data and spatial distribution**
   - Soil texture, organic matter, bulk density (as required by crop model)

↓

4. **Cropping systems and crop management**
   - Sowing date, cultivar maturity, and plant population for each crop in the cropping system (single, double, triple crops per year)

↓

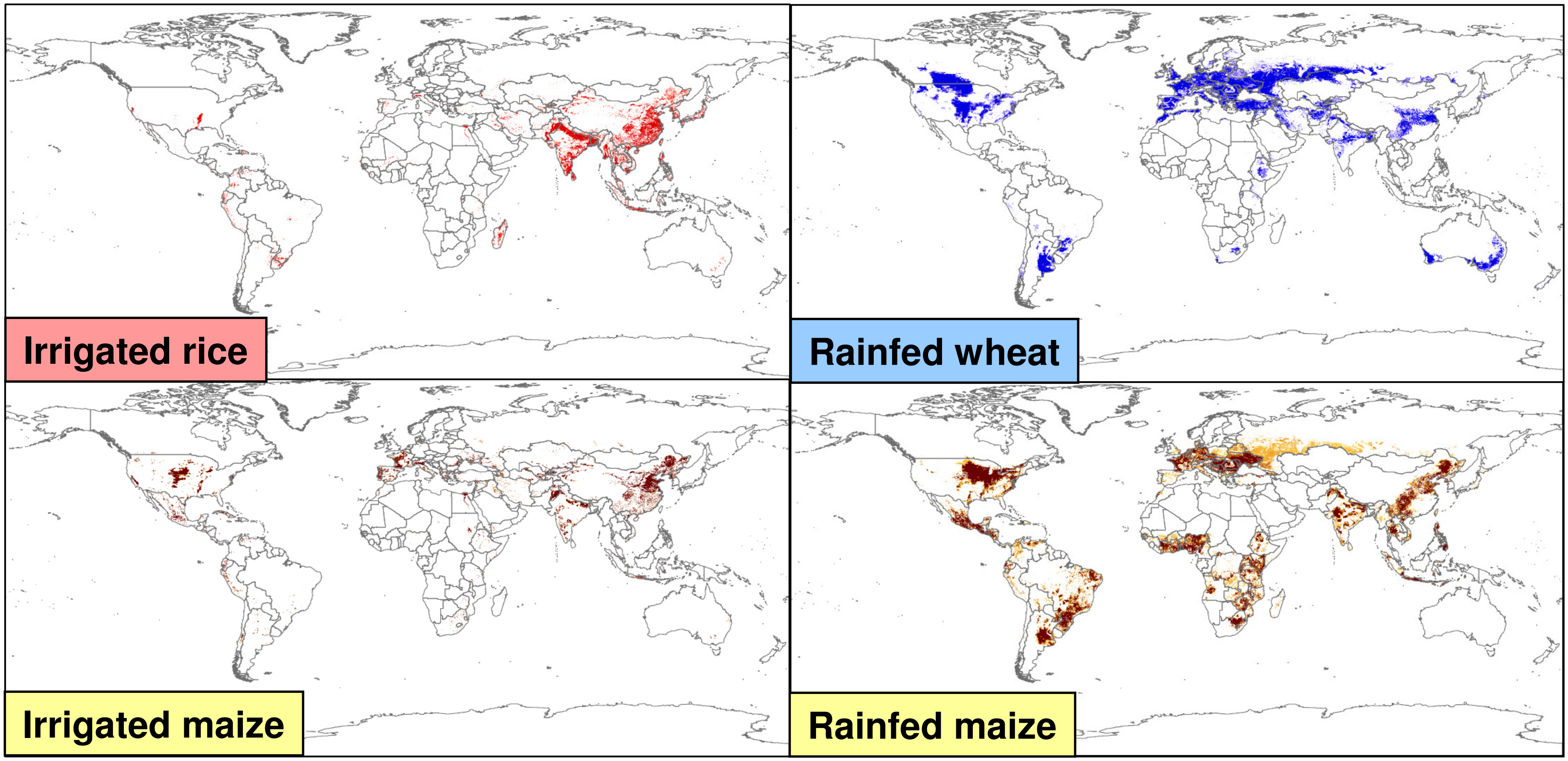
5. **Appropriate crop simulation model**
   - Peer-reviewed, publicly available, limited requirement for genotype-specific parameters, validated against crop yields that approach Yp

↓

6. **Regional or national Yp estimation**
   - Weighted by production potential (harvested area x Yp)

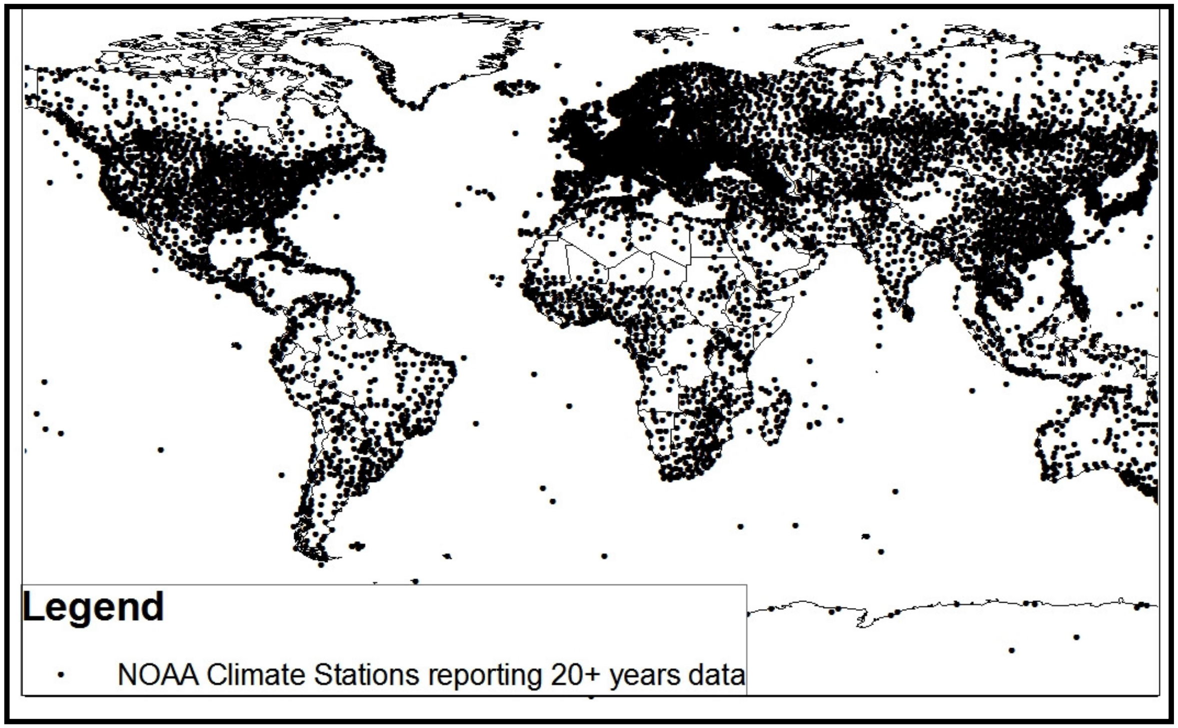
Step 1: Crop harvested area distribution

Source: Portmann, F. T., Siebert, S. & Döll, P. (2010): MIRCA2000 – Global monthly irrigated and rainfed crop areas around the year 2000: A new high-resolution data set for agricultural and hydrological modeling, *Global Biogeochemical Cycles*, 24, GB 1011. Available URL: http://www.geo.uni-frankfurt.de/ipg/ag/dl/forschung/MIRCA/index.html.

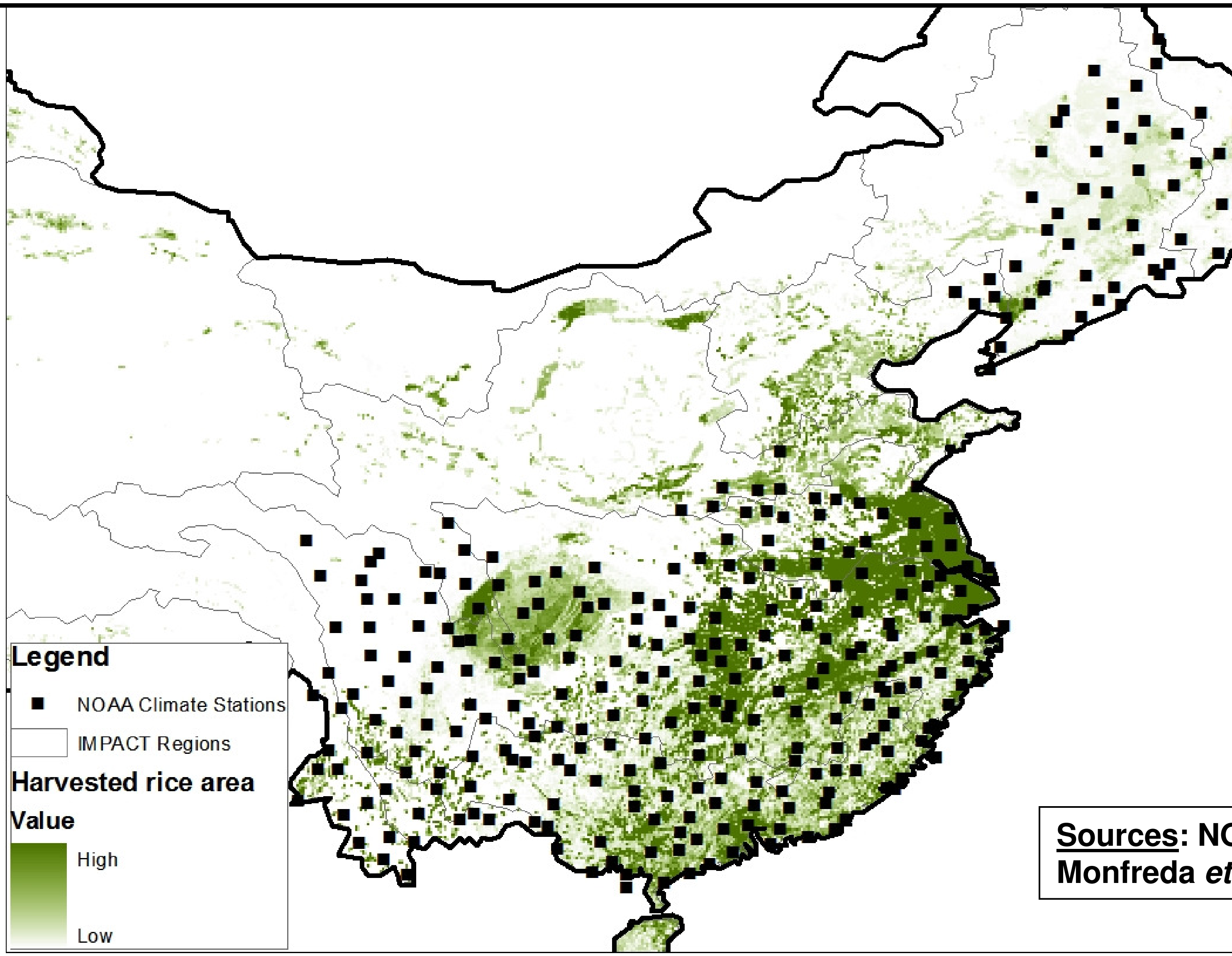


Step 2: Weather data

- **Simulated, spatially interpolated, or monthly averaged weather data leads to poor estimates, especially at higher yield levels (Soltani and Hoogenboom, 2007; van Bussel *et al.*, 2011)**
- **Therefore, NOAA (GSOD) weather stations were used (daily Tmin, Tmax, precipitation, and wind speed) in combination with NASA-measured solar radiation**

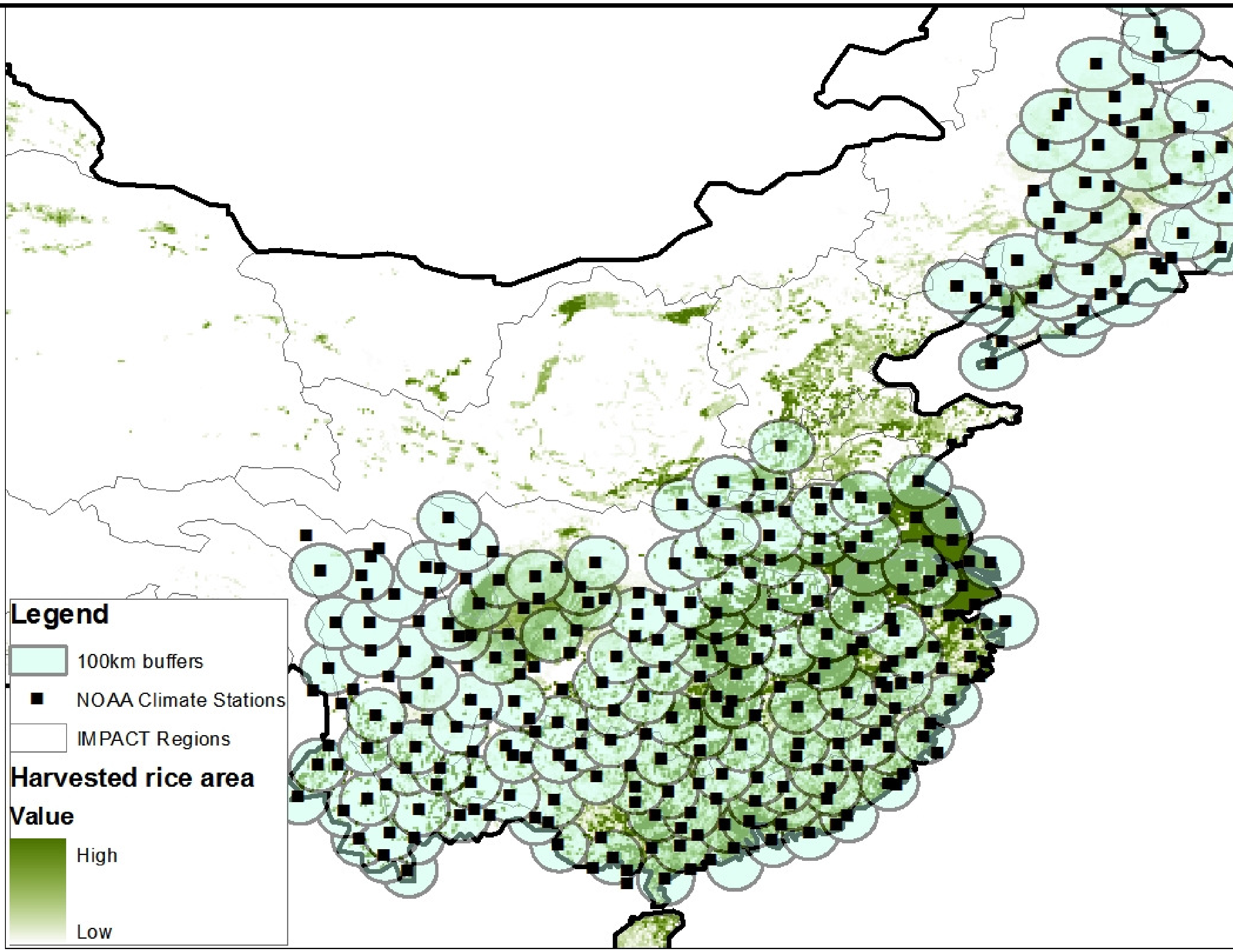


Step 2. (a) identify potential reference weather stations (RWS) in provinces with >2% total national production. Example: Rice in China

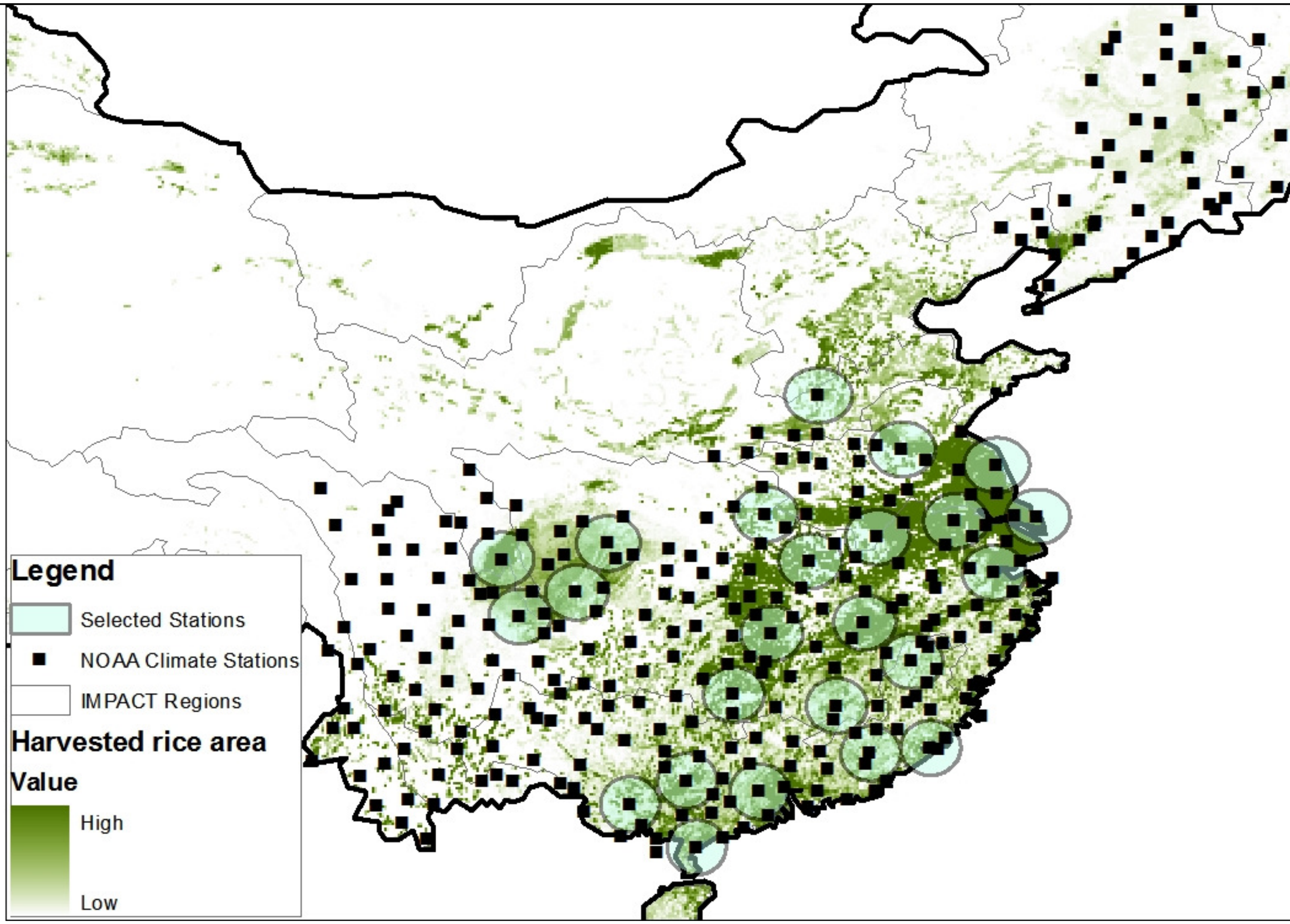


Sources: NOAA and Monfreda *et al.*, 2008

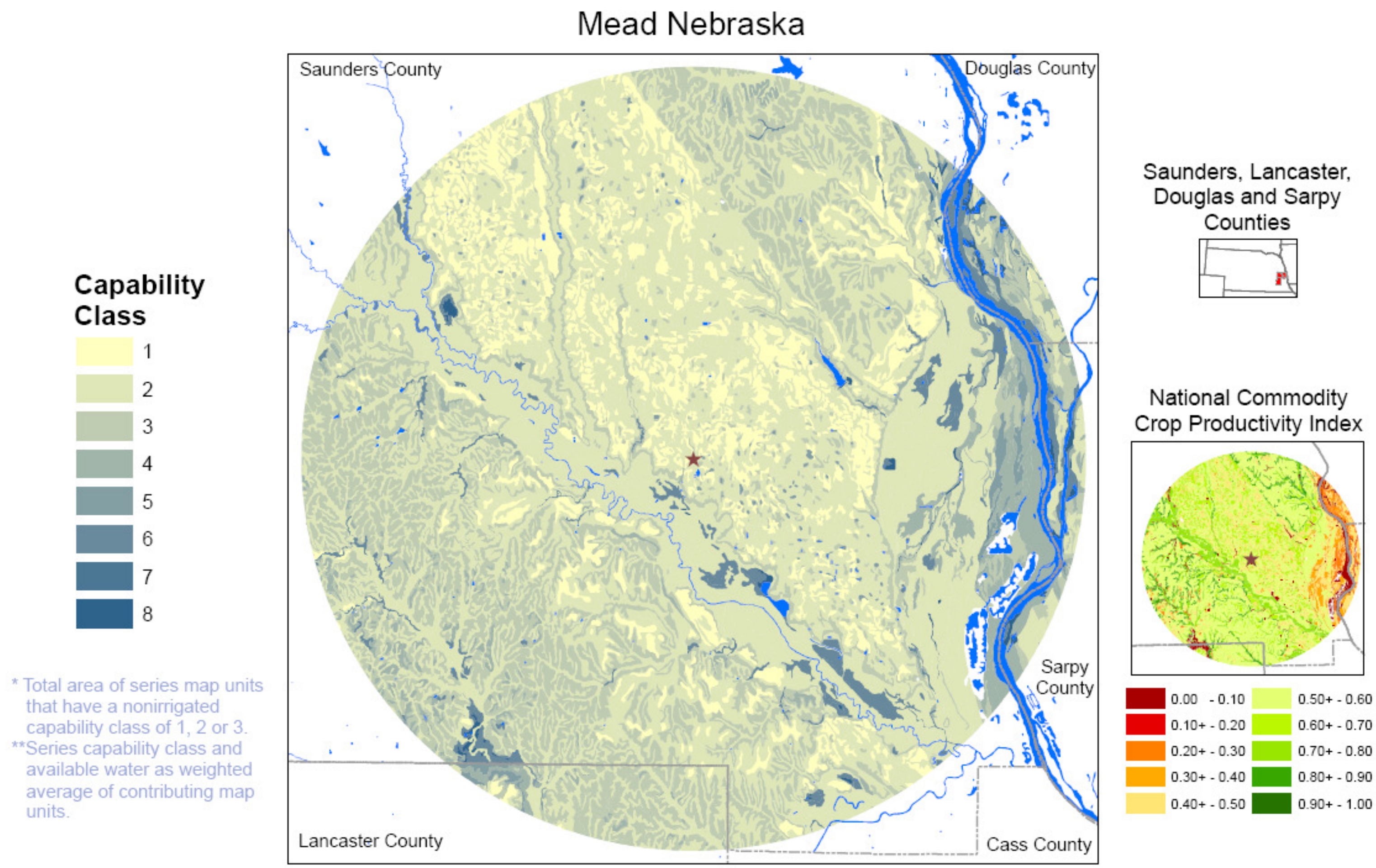
Step 2. (b) Sum harvested area within 100km of each station and rank weather stations by harvested area

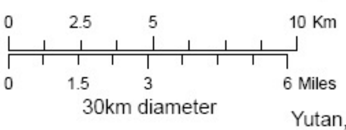


Step 2. (c) Select weather station with greatest rice area, evaluate weather data quality (ideally <10% missing data; <30 consecutive days missing). Then, eliminate all stations within 200km of selected RWS and select next highest ranked station, repeating the above process until >50% of total harvested area is covered by 100-km buffers around RWS



Step 3: Soil properties data





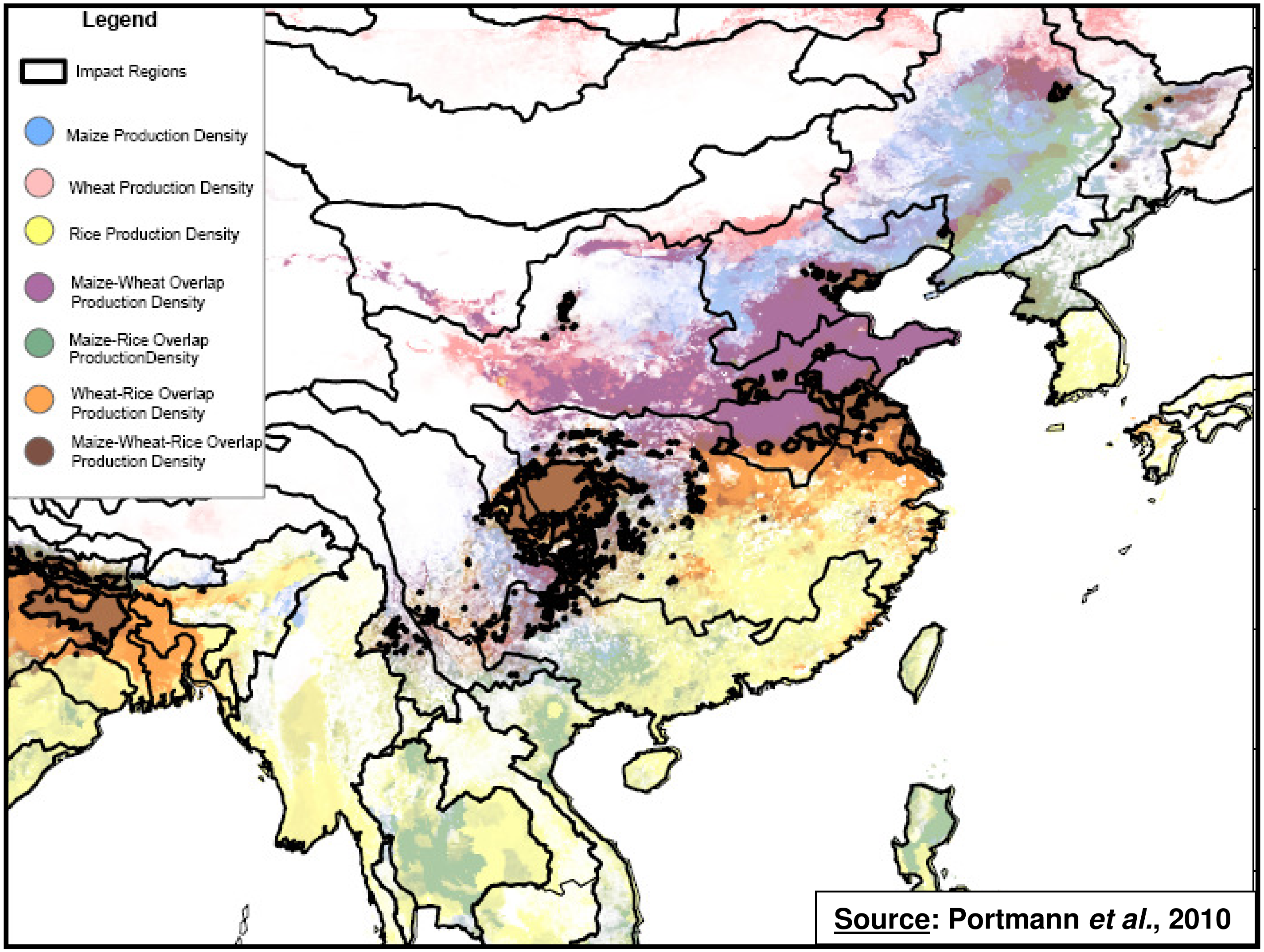
Dominant Nonirrigated Capability Class

Dominant Soil Map Unit	Map Unit Area	Series Area*	Capability Class**	AW** 150cm
Yutan, Eroded-Judson Complex, 5 To 11% Slopes	28523ac	28523ac	3	29.28
Yutan Silty Clay Loam, Terrace, 2 To 5% Slopes, Eroded	19132ac	19928ac	2	28.13
Tomek Silt Loam, 0 To 2% Slopes	16012ac	16012ac	1	27.25

Source: SSURGO database, USDA-NRCS

Step 4: Cropping system and management

Simulated yield potential must be based on current agronomic practices within existing cropping systems. In this example, complex cropping systems with maize, rice, and wheat grown in the same year in China



Source: Portmann *et al.*, 2010

China: 44 systems in 17 provinces with reference weather stations

Province	Cropping season	Crop establish	Seed Variety	Hills per m2	Seeding date	Transplanting date	Flowering date	Maturity date	Area (ha)
Hubei	Early season	Transplanting	IR64	25	01-Apr	28-Apr	25-Jun	18-Jul	266,667
		Direct seeding	IR64		06-Apr		28-Jun	22-Jul	266,667
	Middle season	Transplanting	2You725	21	15-Apr	20-May	10-Aug	15-Sep	533,333
		Direct seeding	2You725		30-Apr		13-Aug	20-Sep	800,000
	Late season	Transplanting	IR64	22.5	18-Jun	22-Jul	10-Sep	15-Oct	200,000
Hunan	Early season	Transplanting	IR64	25	20-Mar	20-Apr	10-Jun	15-Jul	1,133,333
		Direct seeding	IR64		10-Apr		15-Jun	20-Jul	466,667
	Middle season	Transplanting	2You725	22.5	20-Apr	20-May	10-Aug	10-Sep	500,000
	Single late season	Transplanting	2You725	18.4	20-May	20-Jun	15-Aug	30-Sep	366,667
	Double late season	Transplanting	IR64	18.4	20-Jun	20-Jul	10-Sep	20-Oct	1,600,000
Anhui	Early season	Transplanting	IR64	37.5	25-Mar	25-Apr	20-Jun	20-Jul	80,000
		Direct seeding	IR64		15-Apr		15-Jun	15-Jul	186,667
	Middle season	Transplanting	2You501	22.5	10-May	10-Jun	20-Aug	20-Sep	1,466,667
		Direct seeding	2You501		15-Jun		05-Sep	10-Oct	200,000
	Late season	Transplanting	IR64	37.5	15-Jun	15-Jul	20-Sep	20-Oct	300,000
Jiangxi	Early season	Transplanting	IR64	30	25-Mar	25-Apr	20-Jun	20-Jul	1,333,333
		Direct seeding	IR64		01-Apr		20-Jun	20-Jul	133,333
	Middle season	Transplanting	2You501	27	30-Apr	20-May	30-Aug	30-Sep	333,333
	Late season	Transplanting	IR64	27	20-Jun	20-Jul	20-Sep	20-Oct	1,400,000
Guangdong	Early season	Transplanting	IR64	22.5	05-Mar	05-Apr	05-Jun	05-Jul	1,000,000
	Late season	Transplanting	IR72	22.5	18-Jul	03-Aug	30-Sep	05-Nov	1,000,000
Sichuan	Single season	Transplanting	2You501	16	05-Apr	05-May	20-Jul	01-Sep	2,666,667
Guangxi	Early season	Transplanting	IR64	30	01-Mar	01-Apr	16-Jun	15-Jul	1,000,000
	Middle season	Transplanting	2You501	28.5	15-Apr	15-May	10-Jul	10-Aug	133,333
	Late season	Transplanting	IR64	27	10-Jul	05-Aug	01-Oct	05-Nov	1,000,000
Fujian	Early season	Transplanting	IR64	22.5	10-Mar	10-Apr	10-Jun	10-Jul	233,333
	Middle season	Transplanting	IR72	18	20-Apr	20-May	20-Aug	30-Sep	533,333
	Late season	Transplanting	IR72	19.5	15-Jun	15-Jul	10-Sep	15-Oct	233,333
Jiangsu	Single season	Transplanting	Wuxiangjing 9	25.5	15-May	15-Jun	25-Aug	15-Oct	1,200,000
		Direct seeding	Wuxiangjing 9		10-Jun		05-Sep	15-Oct	800,000
Jilin	Single season	Transplanting	Jin Dao 305	22.5	15-Apr	17-May	01-Aug	25-Sep	733,333
Heilongjiang	Single season	Transplanting	Jin Dao 305	24	15-Apr	15-May	25-Jul	20-Sep	2,600,000
Liaoning	Single season	Transplanting	Jin Dao 305	22.5	15-Apr	20-May	10-Aug	01-Oct	666,667
Henan	Single season	Transplanting	XD90247	20.5	01-May	10-Jun	25-Aug	05-Oct	633,333
Zhejiang	Early season	Transplanting	IR64	30	30-Mar	20-Apr	20-Jun	15-Jul	93,333
		Direct seeding	IR64		10-Apr		23-Jun	18-Jul	40,000
	Middle season	Transplanting	Wuxiangjing 9	20	30-May	25-Jun	25-Aug	05-Oct	333,333
		Direct seeding	Wuxiangjing 9		05-Jun		05-Sep	20-Oct	333,333
	Late season	Transplanting	IR64	22.5	15-Jun	23-Jul	15-Sep	20-Oct	200,000
Yunan	Single season (japon	Transplanting	Jin Dao 305	55.5	01-Mar	01-May	01-Aug	15-Sep	600,000
	Single season (indica	Transplanting	2You501	55.5	01-May	01-Jun	01-Sep	05-Oct	333,333
	Upland rice	Direct seeding	HD297		30-Apr		15-Aug	30-Sep	100,000
Guizhou	Single season	Transplanting	2You725	15	05-Apr	20-May	10-Aug	20-Sep	733,333
Hainan	Early season	Transplanting	IR64	33	25-Jan	20-Feb	25-Apr	25-May	166,667
	Late season	Transplanting	IR72	33	20-Jun	10-Jul	05-Sep	05-Oct	213,333

Simulate rice Yp for each of these systems; weight regional and national Yp estimate by proportion of total production contributed by each system.

Step 5. Simulation of Yp for each reference weather station

- Use models that are crop-specific, publically available, validated for Yp estimation (ORYZA2000, HybridMaize, CERES-Wheat)
- Estimate or select cultivar-specific coefficients required as input to run these models
- Simulation based on 20+ years of weather data

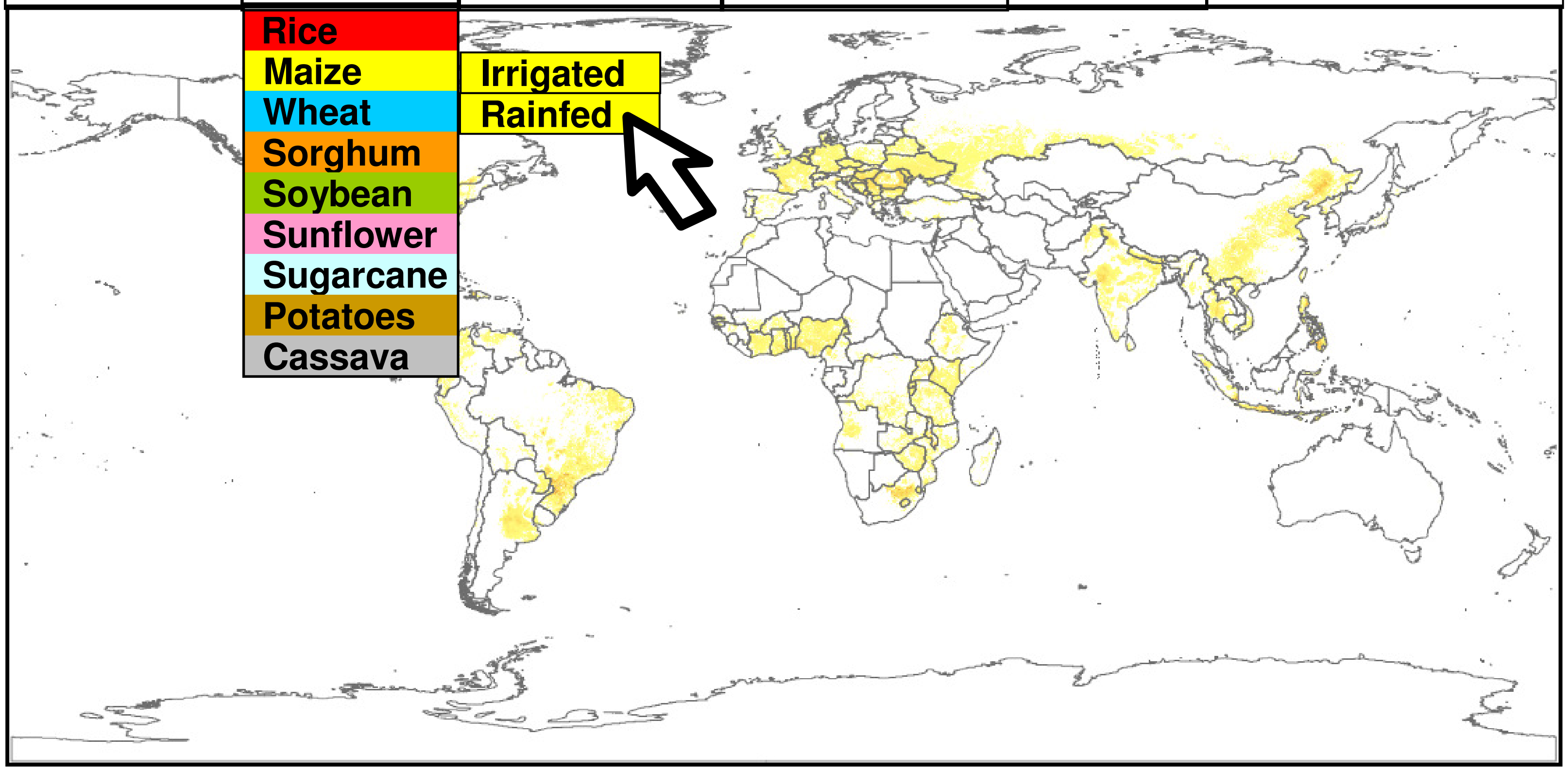
Production-weighted yield potential (Yp) estimates based on current crop management compared to 5-year average national yield (Ya), and coverage of crop area included in Yp estimates. (Source: J. van Wart, PhD Thesis, Univ. of Nebraska)

Country	Crop	Total harvested area (Mha)	% of total area covered by buffers	Ya† (t/ha)	Yp (t/ha)	Ya/Yp (%)
China	Irrigated rice	29.1	51%	6.4	7.5	85%
United States	Rainfed maize	27.7	50%	9.7	13.2	73%
	Irrigated maize	3.5	54%	11.7	15.1	77%
Germany	Rainfed wheat	3.1	52%	7.6	9.5	80%

† US data from USDA-NASS (2004-2008); China and Germany data from FAOSTAT (2004-2008)

Yield Gap and Water Productivity Atlas

Global map	Crop area	Current yield	Yield potential	Yield gap	Water productivity



(1) **Select item from top menu bar, then, select the crop species from drop-down menu, then, select the water regime and the information will be displayed on the map.**

(2) **Alternatively, move the cursor over a specific country to retrieve national-level statistics. The selected country will be highlighted and a table will pop up showing actual and potential production statistics for selected crops, and underpinning data and assumptions.**

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UNITED STATES OF AMERICA – Country level statistics

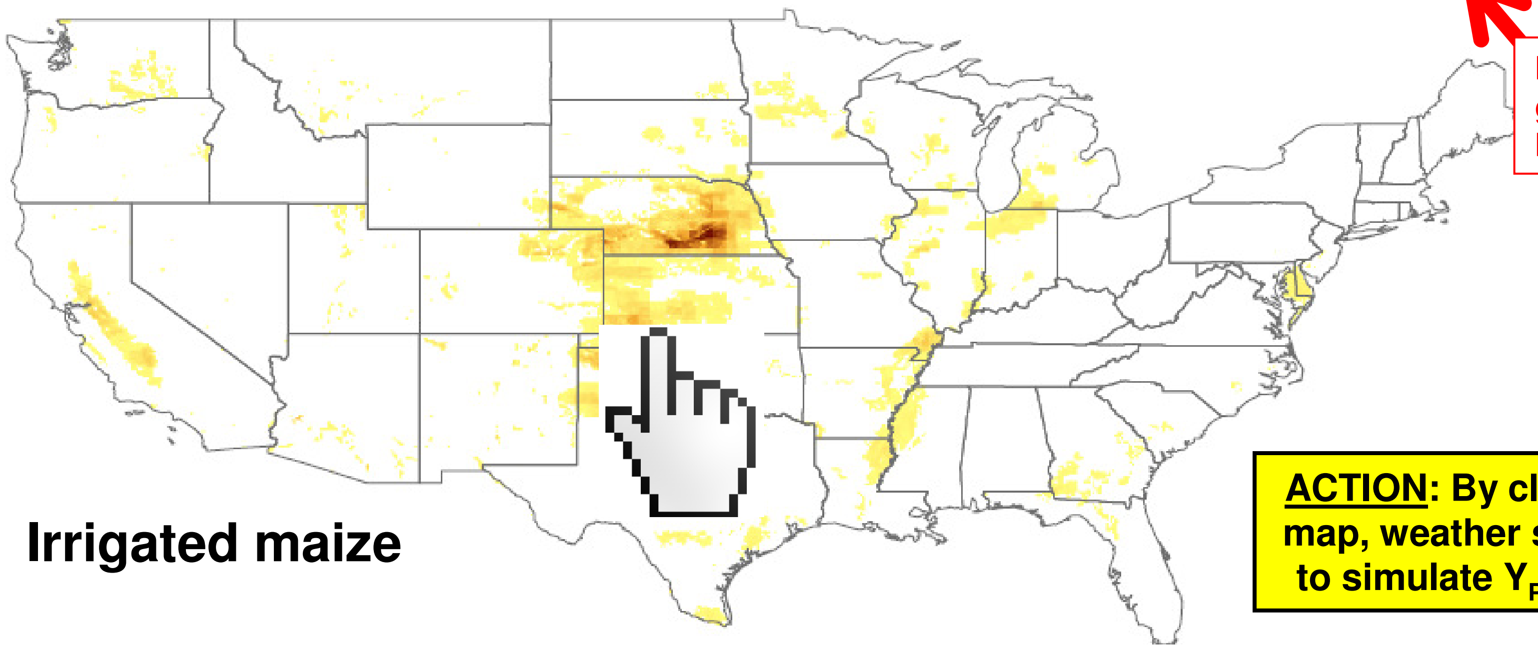
Hot link to FAOSTAT statistics

CROP (global rank)	AREA, million ha	ACTUAL YIELD, t ha^{-1}	YIELD POTENTIAL, t ha^{-1}	YIELD GAP, t ha^{-1} (% of Yp)
Maize (1)	31.6	9.6	XX	YY ()
Soybean (1)	29.2	2.8	XX	YY ()
Wheat (3)	20.5	2.8	XX	YY ()
Sorghum (1)	2.5	4.2	XX	YY ()
Rice (11)	1.2	7.8	XX	YY ()
Sunflower (6)	0.9	1.6	XX	YY ()
Potatoes (4)	0.4	44.6	XX	YY ()
Sugarcane (11)	0.4	75.9	XX	YY ()

Once a country is selected, click on a specific crop to see harvested area distribution for the selected country and the parameters used to simulate yield potential (Yp) (next slide)

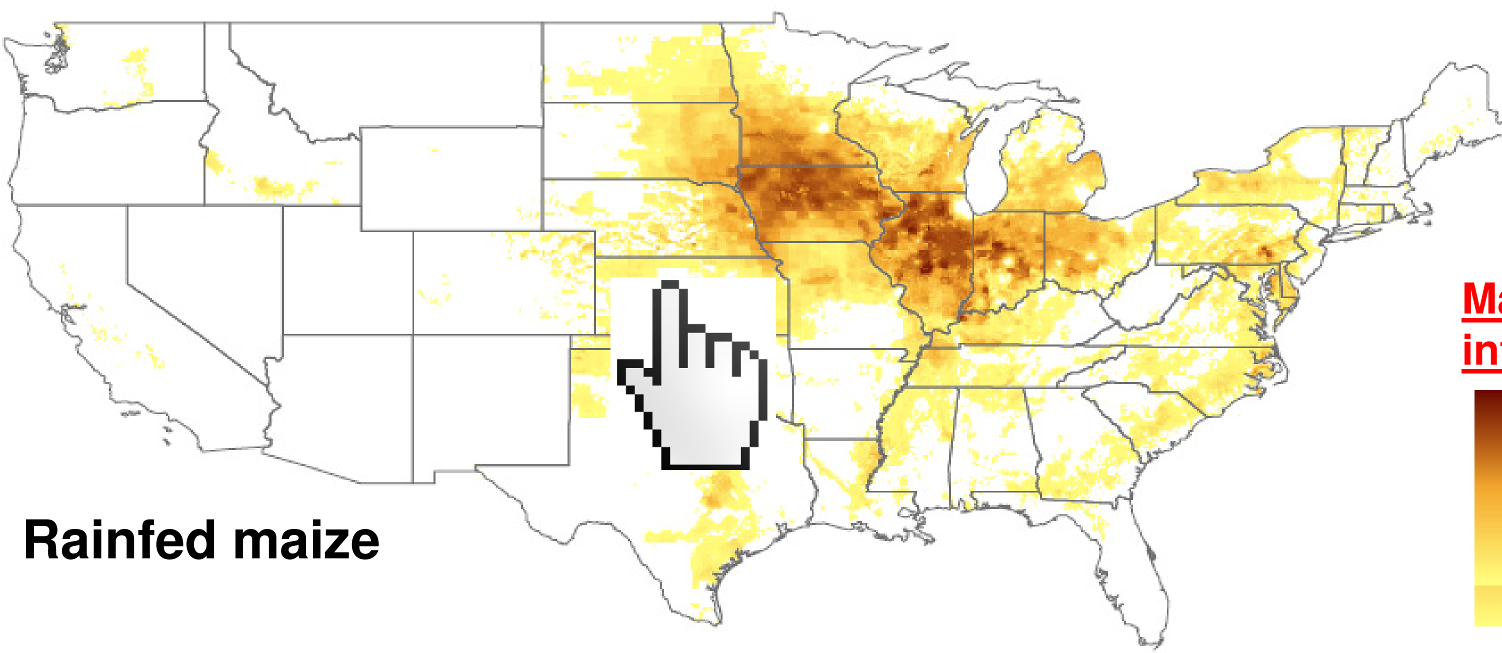
Distribution of harvested irrigated and rainfed US maize area

Hot link to geospatial crop harvest area layers



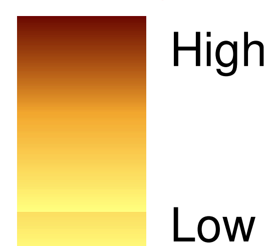
Irrigated maize

ACTION: By clicking on the map, weather stations used to simulate Y_P will pop-up.



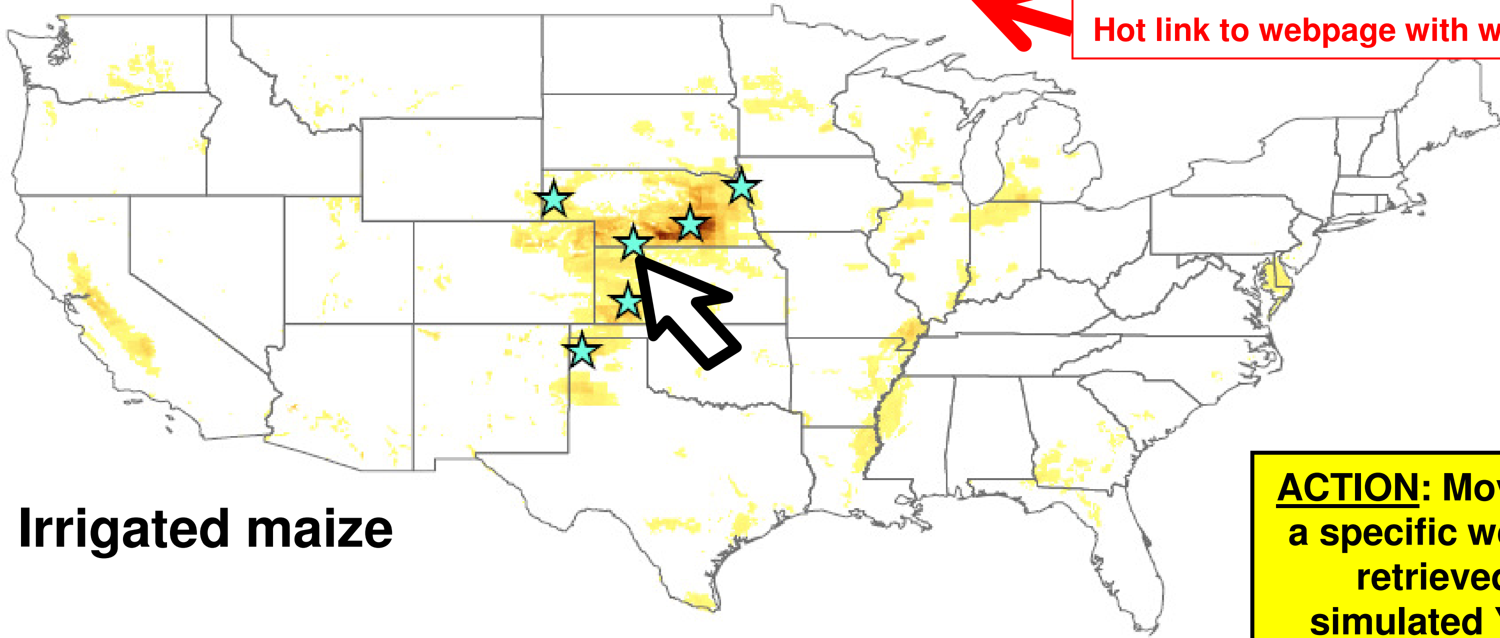
Rainfed maize

Maize cropping intensity:



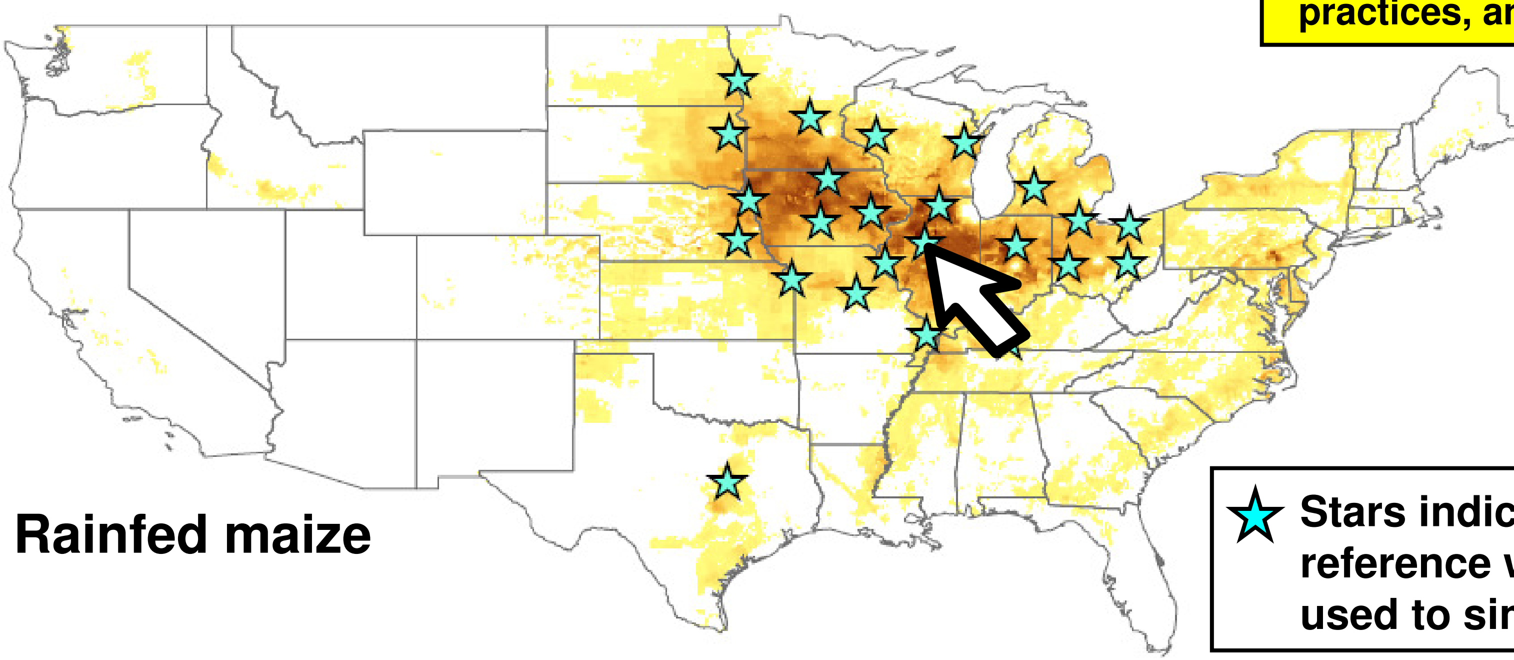
Reference weather stations to simulate Yp of US maize

Hot link to webpage with weather data



Irrigated maize

ACTION: Move the cursor over a specific weather stations to retrieved site-specific simulated Y_P, management practices, and soil properties

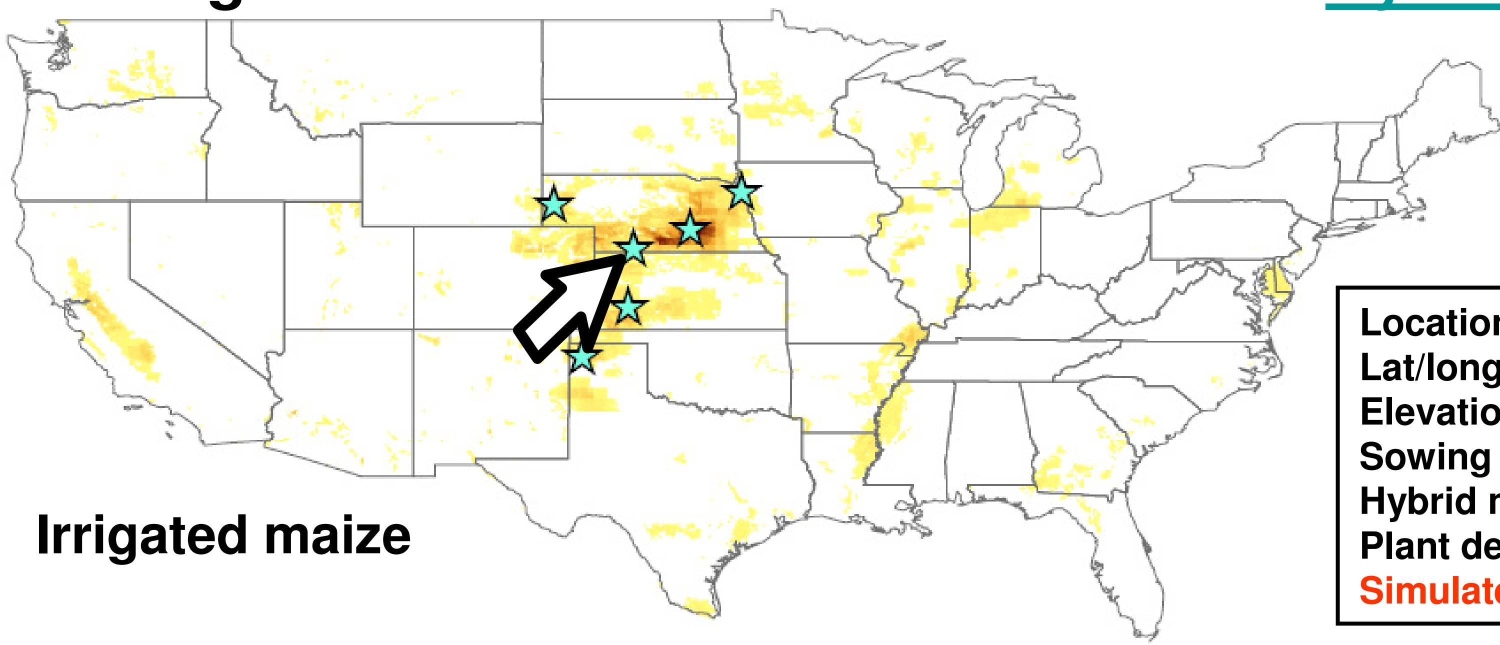


Rainfed maize

Stars indicate location of reference weather stations used to simulate Y_P

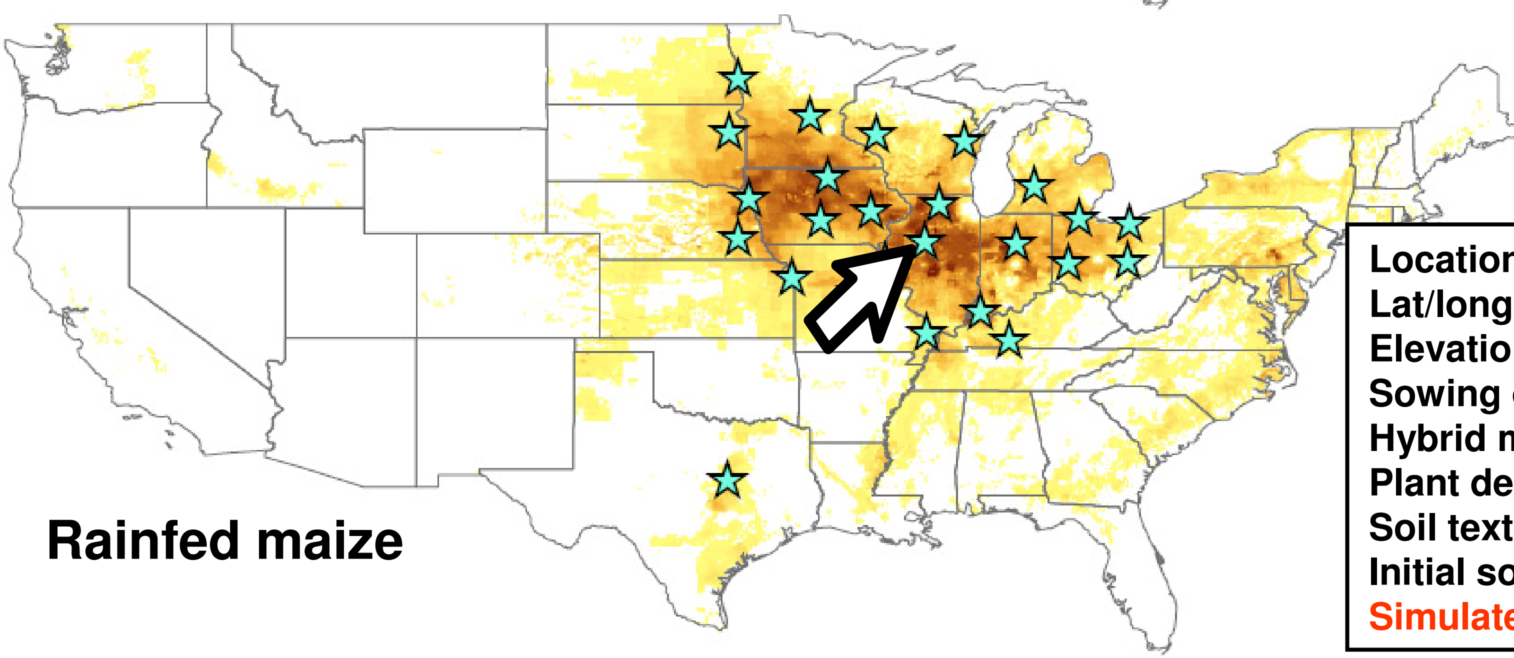
Input parameters to simulate yield potential of irrigated and rainfed maize in USA with Hybrid-Maize

Hot link to information about HybridMaize model



Irrigated maize

Location: McCook, NE
Lat/long: 40.2ºN; 100.2ºW
Elevation: 782 m
Sowing date: May 6
Hybrid maturity: 110 d
Plant density: 79.1k ha^{-1}
Simulated Y_P: 14.3 t ha^{-1}



Rainfed maize

Location: Greater Peoria, IL
Lat/long: 40.7ºN; 89.7ºW
Elevation: 202 m
Sowing date: April 30
Hybrid maturity: 112 d
Plant density: 79.1k ha^{-1}
Soil texture: silt loam
Initial soil water: 100%PAW
Simulated Y_P: 14.2 t ha^{-1}

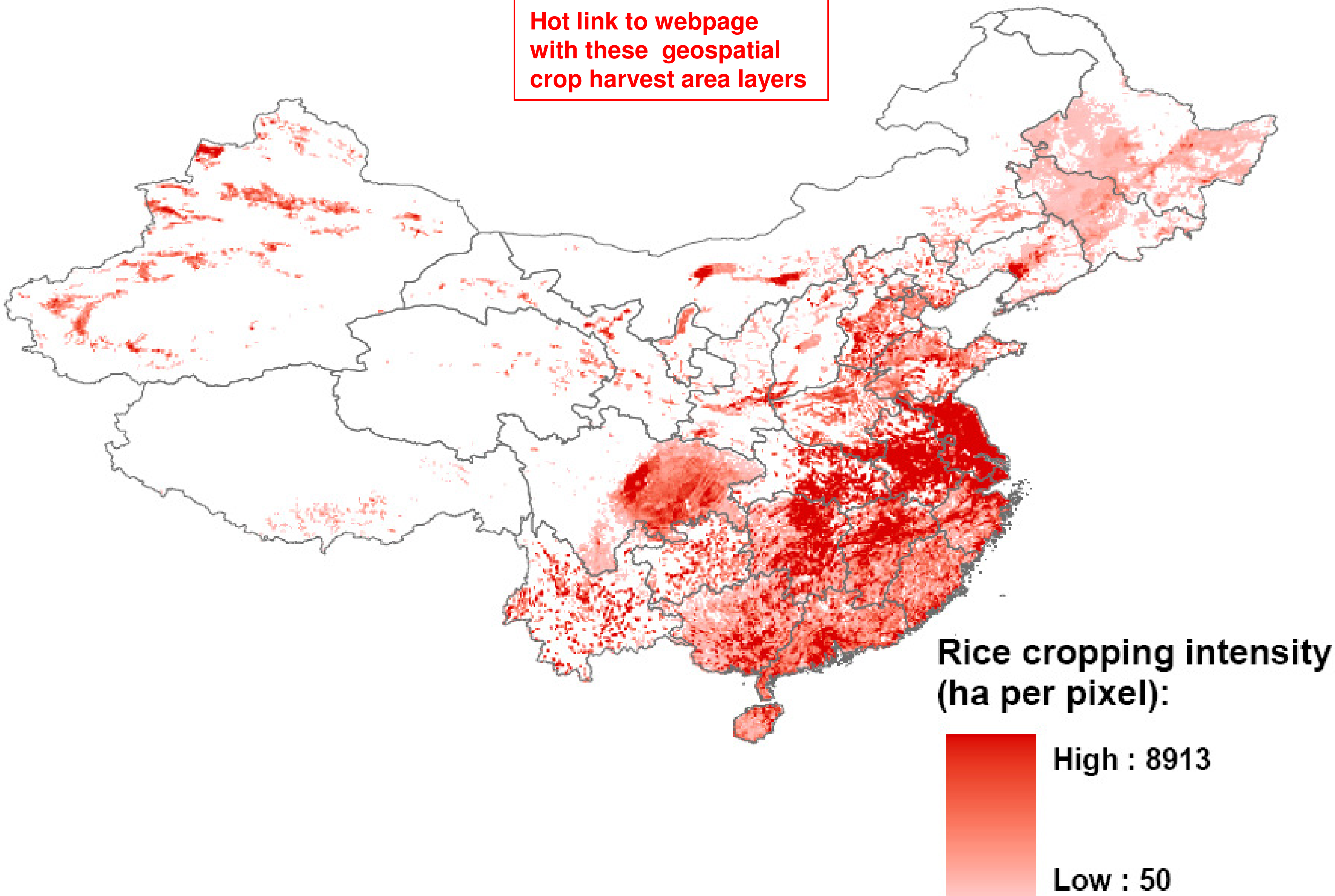
PEOPLE'S REPUBLIC OF CHINA – Country level statistics

CROP (global rank)	AREA, million ha	ACTUAL YIELD, t ha^{-1}	YIELD POTENTIAL, t ha^{-1}	YIELD GAP, t ha^{-1} (% of Yp)
Rice (1)	29.4	6.4	XX	YY
Maize (2)	28.9	5.3	XX	YY
Wheat (1)	23.6	4.6	XX	YY
Soybean (4)	9.6	1.6	XX	YY
Potatoes (1)	4.6	14.3	XX	YY
Sugarcane (3)	1.5	68.7	XX	YY
Sunflower (4)	0.9	1.8	XX	YY
Sorghum (7)	0.6	4.5	XX	YY

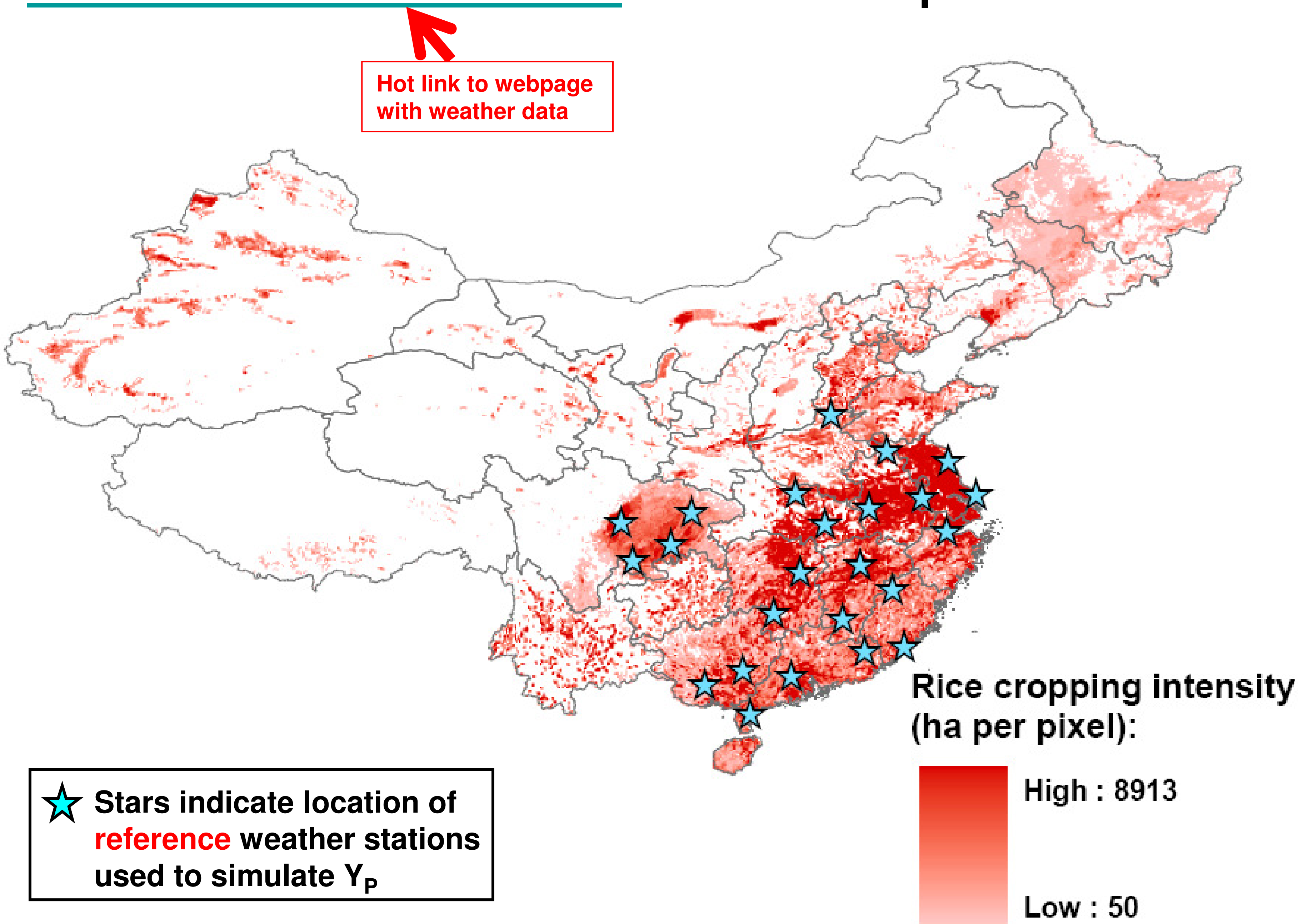
Hot link to FAOSTAT statistics

Distribution of harvested area irrigated rice in China

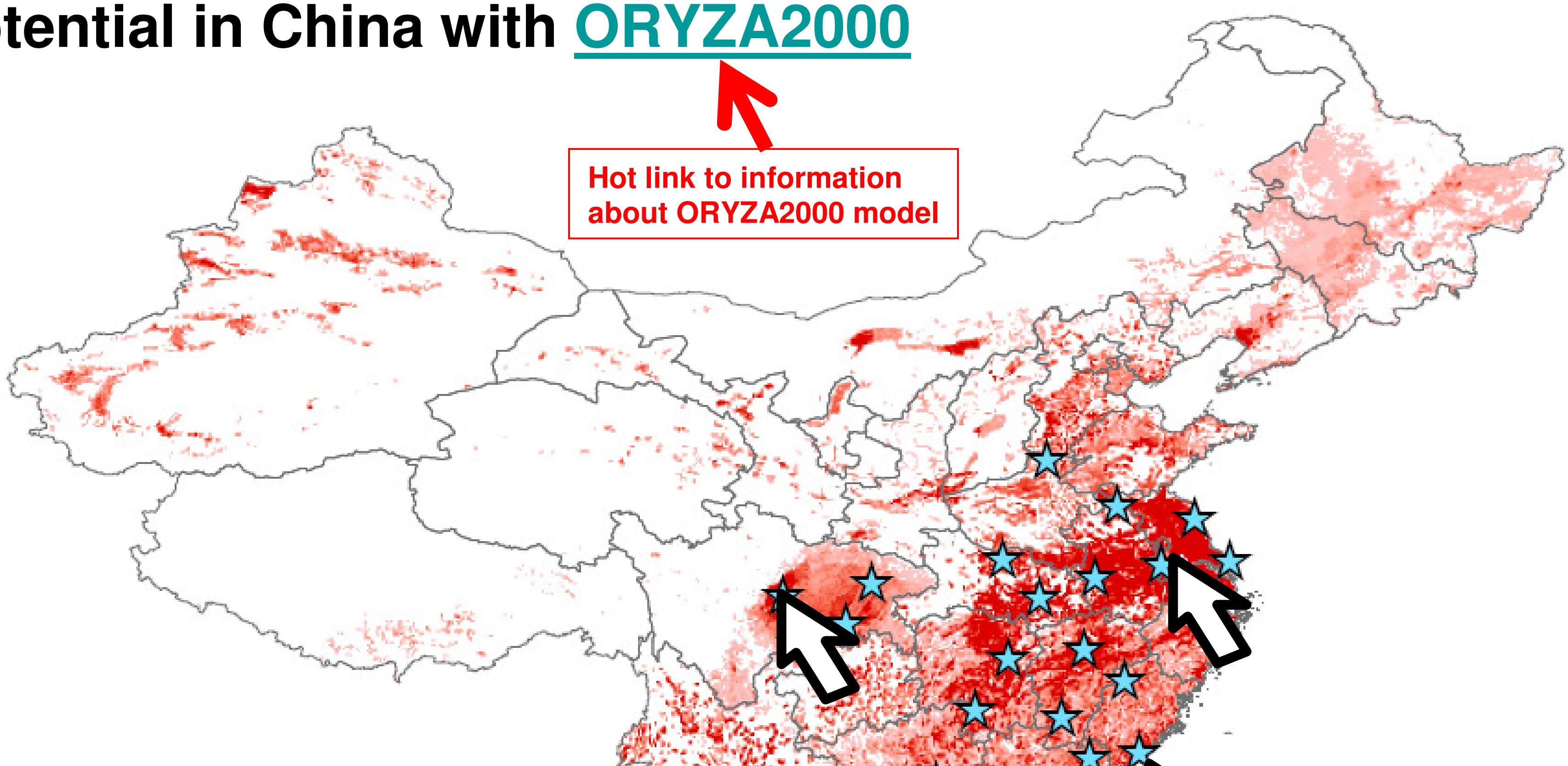
Hot link to webpage
with these geospatial
crop harvest area layers



Reference weather stations to simulate Yp of rice in China



Input parameters to simulate rice yield potential in China with ORYZA2000



Hot link to information about ORYZA2000 model

Location: Xiamen, Fujian (24.5ºN; 118.1ºE). Cropping systems: early-, middle-, and late-season rice

Early-season rice (23% of rice cropland). Simulated Y_P: 4.1 t ha^{-1}

Crop establishment: transplanting; Plant density: 22.5 hills m^{-2}. Seed variety: IR64

Phenology: seeding (Mar 27), emergence (Apr 12), transplanting (May 5), flowering (Jun 15), PM (Jul 15)

Middle-season rice (53% of rice cropland). Simulated Y_P: 8.7 t ha^{-1}

Crop establishment: transplanting; Plant density: 18.0 hills m^{-2}. Seed variety: IR72

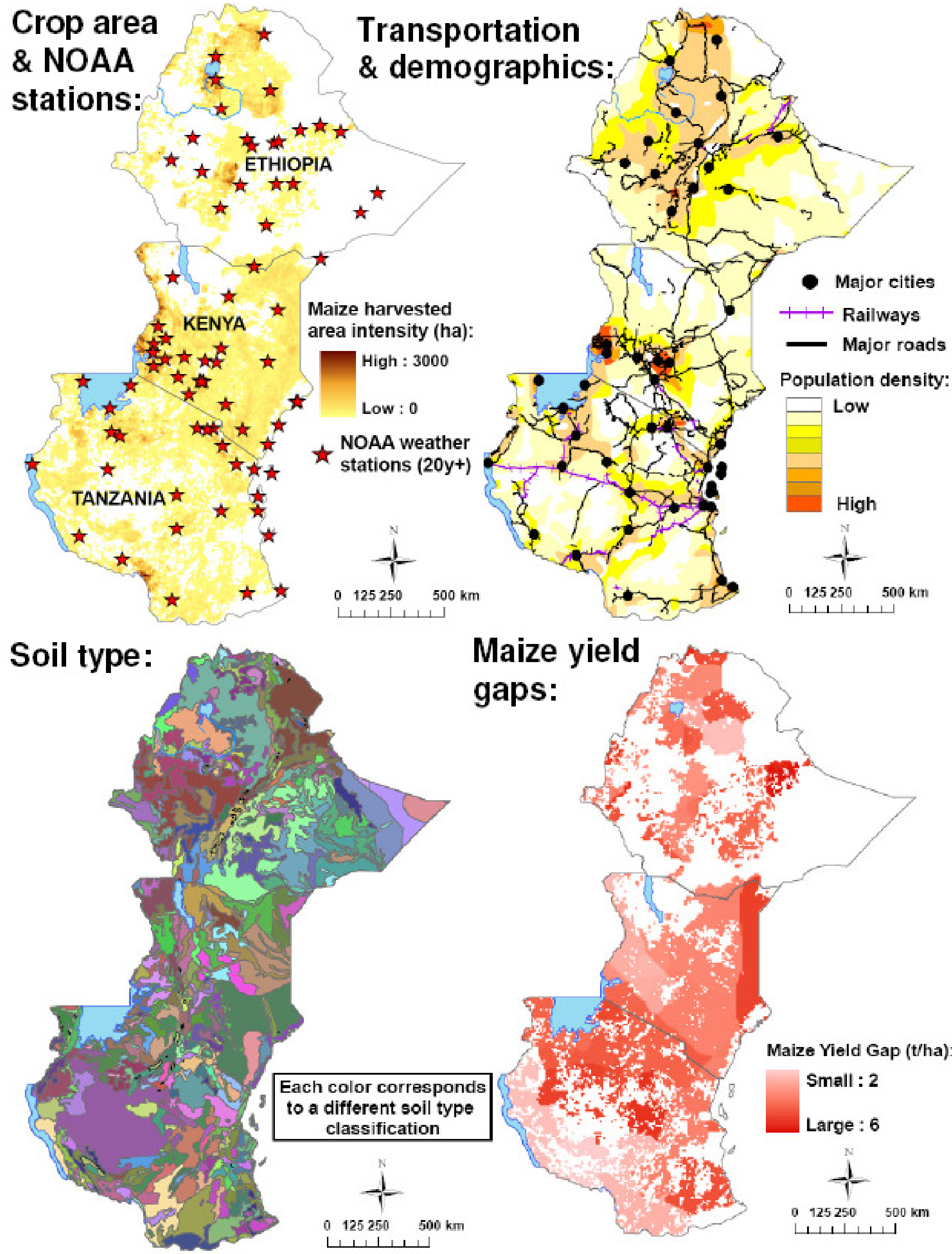
Phenology: seeding (Apr 25), emergence (May 2), transplanting (May 25), flowering (Aug 25), PM (Sep 30)

Late-season rice (23% of rice cropland). Simulated Y_P: 8.9 t ha^{-1}

Crop establishment: transplanting; Plant density: 19.5 hills m^{-2}. Seed variety: IR72

Phenology: seeding (Jun 15), emergence (Jun 22), transplanting (Jul 20), flowering (Sep 20), PM (Oct 25)

Identification of areas with large yield gaps can help guide investment on extension education, road and irrigation infrastructure, market access, etc. In this slide, a hypothetical example for corn in eastern Africa



Data mapped by Grassini, P. (2011)

Summary

- **It is possible to achieve robust, transparent, relevant estimations of Yp at regional and national levels**
  - **Important for accurate estimation of future food production capacity and indirect land use change under different scenarios (climate change, biofuels)**
  - **Critical to inform policy, prioritize research, and benchmark performance for impact assessment**
- **Yp estimates can be used to predict where and when crop yields are likely to plateau**
- **Depending on crop species, initial results confirm a hypothesis that average farm yields plateau when they reach ~75% to 85% of Yp**

Thank you!

Questions?